

Portrait-Bust of Prof. Thomas Egleston, by William Couper, to be Placed in
the Memorial Hall of Columbia-University, New York,
as the Gift of the Students.

TRANSACTIONS
OF THE
AMERICAN INSTITUTE OF MINING
ENGINEERS.

VOL. XXX.

FEBRUARY, 1900, TO SEPTEMBER, 1900.

INCLUSIVE.

NEW YORK CITY:
PUBLISHED BY THE INSTITUTE,
AT THE OFFICE OF THE SECRETARY.

1901.

P R E F A C E.

As explained on p. 1102, it has been found necessary to carry forward to the next volume several papers which properly belong to this one, including the Biographical Notice of Prof. Thomas Egleston, by George F. Kunz, New York City. But the picture of the memorial bust of Prof. Egleston, accompanying that Notice, has been included as a frontispiece in the present volume.

The reader will note, also, that some contributions, strictly to be regarded as "Discussions," are here printed among the "Papers," for reasons given in footnotes attached to them. In connection with these apparent irregularities, a brief statement of the principles governing the arrangement of these volumes is deemed appropriate and timely.

The supreme, controlling object in this work is the perfect accuracy, in all respects, of the published Transactions. In view of the wide distribution, throughout many countries, of the authors of papers, this is not an easy task. It requires, in the first place, that the papers should not be stereotyped, and that the "lineotype" or other cheap methods of type-setting should not be employed; because it is necessary to keep the text of the *Transactions*, to the last moment before printing the volume, open for corrections, additions, etc., which may destroy altogether the arrangement of the pages. As a consequence, the printer of the Institute is required to carry a very large amount of "standing type," sometimes aggregating more than 750 pages, for a period ranging from three to eighteen months. The latter is, of course, a rare maximum; but it might occur, for instance, if a paper by an author in some remote country were read at a February meeting, and his final corrections were not received until just before the volume was issued, in the summer of the following year.

Obviously, it becomes necessary, in order to diminish the risk and cost of keeping so much type standing, to print the sheets of the volume as fast as practicable, so as to release the

type for further use. This printing goes on continuously. At the time of closing the present volume, for instance, several hundred pages of the next have been printed, and the sheets for the whole edition of that portion have been stored. Nor can such printing of any one paper be delayed because some other one is not ready for final issue.

This condition has become imperative since the great increase in the bulk of the annual volume began. In obedience to it, the present Secretary, seventeen years ago, abandoned the original arrangement, by which the Proceedings of each meeting were followed by its Papers and Discussions; and, soon after, sacrificed the former practice of appending to each paper its discussion. It was not possible to hold in type papers ready for final publication until all those of a preceding meeting were similarly ready, or to hold a paper until the last discussion of it had been received, edited and finally approved. Consequently, the Discussions were put together at the end of the volume. But even this arrangement is not always practicable, when the contributions to a discussion are voluminous. Some of them may be kept in type for more than a year, waiting for the completion of the "Papers" of the volume. It may be observed, in passing, that for this reason the apparent amount of the "Discussions" at the end of any volume is not a measure of the amount of actual discussion therein printed. A much greater amount may be found, often in the nominal form of separate papers, in the preceding pages of the volume.

In brief, the order of the contents of these volumes represents essentially the order in which the separate papers, etc., have been brought to a satisfactory degree of perfection for final printing. The "Discussions" are put last, so far as this arrangement is practicable, so that a place may remain for contributions of this class to the last moment before final printing. And the deficiency in logical arrangement or classification among the miscellaneous contents of each volume is made up in part by the full Table of Contents, and in still greater part by the elaborate and minute alphabetical analytical index, which is believed to furnish a much more complete and efficient guide to the reader.

The following separate volumes, now in preparation, will be issued during the present year:

1. An Analytical Index of Vols. XXVI. to XXX., inclusive. This will be sent to members free.

2. A special volume on Ore-Deposits, to contain the material of the "Posepny volume," now out of print, together with the important papers and discussions on the subject, since contributed to the Institute.

3. A special volume on Mine-Surveying Instruments, containing the paper of Mr. Dunbar D. Scott (*Trans.*, xxviii.), and many other contributions and discussions since received (including the papers mentioned on p. 1102 of this volume as held for Vol. XXXI.).

R. W. RAYMOND.

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For year ending February, 1901.*

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* The following officers were elected at the Annual Meeting, February, 1901: *President*, E. E. Ocott, New York City; *Vice-Presidents* (to serve two years), C. F. de Landero, Pachuca, Mexico; J. E. Hardman, Montreal, Canada; J. H. Hammond, Denver, Colo.; *Managers* (to serve three years), G. A. Crocker, New York City; H. V. Winchell, Butte, Mont.; Clemens Catesby Jones, Richmond, Va.; *Treasurer*, Theodore D. Rand, Philadelphia, Pa.; *Secretary*, Rossiter W. Raymond, New York City.

LIST OF THE MEETINGS OF THE INSTITUTE AND THEIR LOCALITIES FROM ITS ORGANIZATION TO AUGUST, 1900.

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			Vol.	Page
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II.	Bethlehem, Pa.	August, 1871	i.	10
III.	Troy, N. Y.	November, 1871	i.	13
IV.	Philadelphia, Pa.	February, 1872	i.	17
V.	New York, N. Y.*	May, 1872	i.	20
VI.	Pittsburg, Pa.	October, 1872	i.	25
VII.	Boston, Mass.	February, 1873	i.	28
VIII.	Philadelphia, Pa.*	May, 1873	ii.	3
IX.	Easton, Pa.	October, 1873	ii.	7
X.	New York, N. Y.	February, 1874	ii.	11
XI.	St. Louis, Mo.*	May, 1874	iii.	3
XII.	Hazleton, Pa.	October, 1874	iii.	8
XIII.	New Haven, Conn.	February, 1875	iii.	15
XIV.	Dover, N. J.*	May, 1875	iv.	3
XV.	Cleveland, O.	October, 1875	iv.	9
XVI.	Washington, D. C.	February, 1876	iv.	18
XVII.	Philadelphia, Pa.†	June, 1876	v.	3
XVIII.	Philadelphia, Pa.	October, 1876	v.	19
XIX.	New York, N. Y.	February, 1877	v.	27
XX.	Wilkes-Barre, Pa.*	May, 1877	vi.	3
XXI.	Amenia, N. Y.	October, 1877	vi.	10
XXII.	Philadelphia, Pa.	February, 1878	vi.	18
XXIII.	Chattanooga, Tenn.*	May, 1878	vii.	3
XXIV.	Lake George, N. Y.	October, 1878	vii.	103
XXV.	Baltimore, Md.*	February, 1879	vii.	217
XXVI.	Pittsburg, Pa.	May, 1879	viii.	3
XXVII.	Montreal, Canada	September, 1879	viii.	121
XXVIII.	New York, N. Y.*	February, 1880	viii.	275
XXIX.	Lake Superior, Mich.	August, 1880	ix.	1
XXX.	Philadelphia, Pa.*	February, 1881	ix.	275
XXXI.	Staunton, Va.	May, 1881	x.	1
XXXII.	Harrisburg, Pa.	October, 1881	x.	119
XXXIII.	Washington, D. C.*	February, 1882	x.	225
XXXIV.	Denver, Col.	August, 1882	xi.	1
XXXV.	Boston, Mass.*	February, 1883	xi.	217
XXXVI.	Roanoke, Va.	June, 1883	xii.	3
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XL.	Philadelphia, Pa.	September, 1884	xiii.	285
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* Annual meeting for the election of officers. The rules were amended at the Chattanooga meeting, May, 1878, changing the annual election from May to February.

† Begun in May at Easton, Pa., for the election of officers, and adjourned to Philadelphia.

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XLV.	Bethlehem, Pa.....	May, 1886.....	xv.	lxiii.
XLVI.	St. Louis, Mo.....	October, 1886.....	xv.	lxx.
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XLIX.	Duluth, Minn.....	July, 1887.....	xvi.	xxiv.
	L. Boston, Mass.*.....	February, 1888.....	xvi.	xxviii.
	LI. Birmingham, Ala.....	May, 1888.....	xvii.	xix.
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	LV. Ottawa, Canada.....	October, 1889.....	xviii.	xxiv.
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* Annual meeting for the election of officers.

† Begun in February at New York City, for the election of officers, and adjourned to Florida.

PUBLICATIONS.

THE publications of the Institute comprise :

PAMPHLETS.

1. The minutes of the Proceedings of each Meeting.

2. Such of the papers presented or read by title at each Meeting as are furnished by the authors and approved by the Council for full publication. (In nearly all cases in which papers, the titles of which appear in the Proceedings, are not subsequently published, they have been withdrawn by the authors.) These papers are published separately in pamphlet form, and are marked "subject to revision." Beyond the edition distributed without charge to members and associates not in arrears, a small supply is retained to meet subsequent demand. There are no copies on hand of papers read before 1880. The stock is nearly complete from 1880. These papers are for sale at the office of the Secretary, or are sent to purchasers by mail or express, charges paid, on receipt of the price, as follows :

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TRANSACTIONS.

The volumes of *Transactions*, which are published annually, contain the list of officers, rules, etc., the Proceedings, and the papers revised for final publication. (In this revision, after the preliminary publication, authors are permitted to use the largest liberty ; and the changes and additions made in papers are sometimes important. It should be borne in mind, by those who study or quote a paper in the preliminary edition, that they may not have in that form the ultimate and deliberate expression of the author's views. It should be added, however, that in the majority of cases there is no important change.) These volumes are for sale as follows, in paper covers :

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RULES

ADOPTED MAY, 1873. AMENDED MAY, 1875, 1877, AND 1878, FEBRUARY, 1880, 1881,
1887, 1890, AND 1896.

I.

OBJECTS.

THE objects of the AMERICAN INSTITUTE OF MINING ENGINEERS are to promote the arts and sciences connected with the economical production of the useful minerals and metals, and the welfare of those employed in these industries, by means of meetings for social intercourse, and the reading and discussion of professional papers, and to circulate, by means of publications among its members and associates, the information thus obtained.

II.

MEMBERSHIP.

The Institute shall consist of Members, Honorary Members, and Associates. Members and Honorary Members shall be professional mining engineers, geologists, metallurgists, or chemists, or persons practically engaged in mining, metallurgy, or metallurgical engineering. Associates shall include all suitable persons desirous of being connected with the Institute, and duly elected as hereinafter provided. Each person desirous of becoming a member or associate shall be proposed by at least three members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) upon receiving three-fourths of the votes cast, and shall become a member or associate on the payment of his first dues. Each person proposed as an honorary member shall be recommended by at least ten members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) on receiving nine-tenths of the votes cast; *Provided*, that the number of honorary members shall not exceed twenty. The Council may at any time change the classification of a person elected as associate, so as to make him a member, or *vice versa*, subject to the approval of the Institute. All members and associates shall be equally entitled to the privileges of membership; *Provided*, that honorary members shall not be entitled to vote, and members or associates whose post-office address shall be outside of the United States, Canada and Mexico shall not be entitled to vote by mail, except upon proposed amendments to the Rules.

Any member or associate may be stricken from the list on recommendation of the Council, by the vote of three-fourths of the members and associates present at any annual meeting, due notice having been mailed in writing by the Secretary to the said member or associate.

III.

DUES.

The dues of members and associates shall be ten dollars, payable upon their election, and ten dollars per annum thereafter, payable in advance on the first day of each calendar year. Honorary members shall not be liable to dues. Any member or associate not in arrears may become by the payment of one hundred dollars at one time a life-member or associate, and shall not be liable thereafter to annual dues. Any member or associate in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members when in arrears for one year; *Provided*, that he may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

IV.

OFFICERS.

The affairs of the Institute shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, a Secretary and a Treasurer, who shall be elected from among the members and associates of the Institute at the annual meetings, to hold office as follows:

The President, the Secretary, and the Treasurer for one year (and no person shall be eligible for immediate re-election as President who shall have held that office subsequent to the adoption of these rules, for two consecutive years), the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected. At each annual meeting a President, three Vice-Presidents, three Managers, a Secretary, and a Treasurer shall be elected, and the term of office shall continue until the adjournment of the meeting at which their successors are elected.

The duties of all officers shall be such as usually pertain to their offices, or may be delegated to them by the Council or the Institute; and the Council may in its discretion require bonds to be given by the Treasurer. At each annual meeting the Council shall make a report of proceedings to the Institute, together with a financial statement.

Vacancies in the Council may occur by death or resignation; or the Council may, by a vote of the majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings or perform the duties of his office. All vacancies shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *Provided*, that the said appointment shall not render him ineligible at the next annual meeting.

Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may be transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to

the approval of a majority of the Council, subsequently given in writing to the Secretary, and recorded by him with the minutes.

V.

ELECTIONS.

The annual election shall be conducted as follows: Nominations may be sent in writing to the Secretary, accompanied with the names of the proposers, at any time not less than thirty days before the annual meeting; and the Secretary shall, not less than two weeks before the said meeting, mail to every member or associate (except honorary members) a list of all the nominations for each office so received, together with a copy of this rule, and the names of the persons ineligible for election to each office; and if the Council, or a Committee thereof, appointed for the purpose, shall have recommended any nominations, such recommendation may also be sent to members and associates with the said list of all nominations made, but not upon the same paper. And each member or associate, qualified to vote, may vote, either by striking from or adding to the names of the said list, leaving names not exceeding in number the officers to be elected, or by preparing a new list, signing said altered or prepared ballot with his name, and either mailing it to the Secretary or presenting it in person at the annual meeting; *Provided*, that no member or associate in arrears since the last annual meeting shall be allowed to vote until the said arrears shall have been paid. The ballots shall be received and examined by three Scrutineers, appointed at the annual meeting by the presiding officer; and the persons who shall have received the greatest number of votes for the several offices shall be declared elected, and the Scrutineers shall so report to the presiding officer. The ballots shall be destroyed, and a list of the elected officers, certified by the Scrutineers, shall be preserved by the Secretary.

VI.

MEETINGS.

The annual meeting of the Institute shall take place on the third Tuesday of February, at which a report of the proceedings of the Institute and an abstract of the accounts shall be furnished by the Council. Other meetings shall be held in each year, at such times and places as the Council shall select, and notice of all meetings shall be given by mail, or otherwise, to all members and associates, at least twenty days in advance.

Every question which shall come before any meeting of the Institute, shall be decided, unless otherwise provided by these Rules, by the votes of a majority of the members then present. Any member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

VII.

PAPERS AND PUBLICATIONS.

The Council shall have power to decide on the propriety of communicating to the Institute any papers which may be received, and they shall be at liberty, when they think it desirable, to direct that any paper read before the Institute shall

be printed in the *Transactions*. Intimation, when practical, shall be given, at each general meeting, of the subject of the paper or papers to be read, and of the questions for discussion at the next meeting. The reading of papers shall not be delayed beyond such hour as the presiding officer shall think proper; and the election of members or other business may be adjourned by the presiding officer, to permit the reading and discussion of papers. The published papers and volumes of *Transactions* shall be distributed to all members and associates not in arrears, and may be sold to the public upon such conditions as the Council shall prescribe; but the Council may, in its discretion, omit sending to members and associates outside of the United States, Canada and Mexico, special circulars, unless the same contain proposed amendments to the Rules.

The copyright of all papers communicated to, and accepted by, the Institute, shall be vested in it, unless otherwise agreed between the Council and the author. The author of each paper read before the Institute shall be entitled to twelve copies, if printed, for his own use, and shall have the right to order any number of copies at the cost of paper and printing, provided said copies are not intended for sale. The Institute is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions at its meetings, and it is understood that papers and discussions should not include matters relating to politics or purely to trade; nor shall the Council or the Institute officially approve or disapprove any technical or scientific opinion or any proposed enterprise outside the management of the meetings, discussions and publications of the Institute, as provided in these Rules; *Provided*, however, that committees may be appointed by the Council or the Institute to make investigations and submit reports at meetings of the Institute; but no action shall be taken binding the Institute for or against the conclusions of any such reports.

VIII.

AMENDMENTS.

These Rules may be amended at any annual meeting by a two-thirds vote of the members present; *Provided*, that written notice of the proposed amendment shall have been given at a previous meeting; and *Provided*, also, that the amendment or amendments so adopted shall be printed upon a ballot and sent, not later than the next distribution of printed matter, to all members and associates not in arrears for the preceding year (except honorary members and foreign members elected before February, 1880), and each person receiving the same shall be requested to return it to the Secretary with his written vote of Yes or No to each amendment, and his signature; and the President shall appoint as Scrutineers three members or associates, who shall examine all of the said ballots which shall have been returned within one month from the date of their distribution, and shall report the result; and the Secretary shall publish and distribute to members, not later than the next distribution of printed matter, an announcement of the said result so reported, together with the text of the additional or amended rule or rules so adopted; and the amendment or amendments approved by the majority of the ballots so returned and reported shall become part of these Rules from and after the publication of said announcement by the Secretary.

Proceedings of the Seventy-Eighth (Thirtieth Annual)
Meeting, Washington, D. C., February, 1900.

COMMITTEES.

Executive Committee.—Hon. Charles D. Walcott, *Chairman*; E. W. Parker, *Secretary*.

Reception Committee.—Arnold Hague, *Chairman*; Dr. Z. T. Sowers, Cabell Whitehead, Dr. Thomas M. Chatard, H. C. Perkins.

Program Committee.—Fred. P. Dewey, *Chairman*; T. C. Walsh, G. L. Bradley, G. Steiger, B. Willis.

Hotels Committee.—Dr. David T. Day, *Chairman*; N. H. Darton, G. C. Gardner, C. E. Hesse, H. W. Turner.

Banquet Committee.—S. F. Emmons, *Chairman*; G. E. Eldridge, Prof. C. E. Munroe, J. Pierce, Jr., E. W. Parker.

Excursion Committee.—C. Willard Hayes, *Chairman*; Alfred E. Jessup, M. R. Campbell, G. K. Gilbert, W. Lindgren.

Finance Committee.—Dr. Thomas M. Chatard, *Chairman*; R. H. Chapman, J. S. Pechin, W. H. Weed, Gifford Pinchot, C. E. Coffin.

Hotel Headquarters.—Arlington Hotel.

The opening session was held on Tuesday evening, February 20th, at the lecture hall of the Columbian University. Hon. Charles D. Walcott, Director of the United States Geological Survey, called the meeting to order and introduced the Hon. John B. Wight, one of the Commissioners of the District of Columbia, who welcomed the visiting members in a brief address. President James Douglas responded on behalf of the Institute.

Messrs. G. F. Knapp, A. W. Sheaffer and Theodore Dwight were appointed Scrutineers to examine the ballots received by mail, and to report the result at a later session.

Hon. Charles D. Walcott, Director of the U. S. Geological Survey, delivered a brief address explaining the work of the Survey in different regions of the United States—a summary of his paper on "The Work of the United States Geological Survey in Relation to the Mineral Resources and Mining Industries of the United States," printed elsewhere.* His remarks were illustrated by a colored map.

* See p. 3.

The President then introduced Mr. G. K. Gilbert, of the Survey, who exhibited and explained a series of colored lantern views of Alaskan scenery, selected from a large number of photographs recently taken by him.

The second session was held in the lecture-hall of the Columbian University at 10 o'clock Wednesday morning, President Douglas presiding.

Prof. C. R. Van Hise, Madison, Wis., read a paper on Some Principles Controlling the Deposition of Ores.

The Secretary presented a synopsis of a paper on Origin and Classification of Ore-Deposits, by Charles R. Keyes, Des Moines, Iowa.

A discussion of Prof. Van Hise's paper followed.

The session concluded with the reading of a paper on The Secondary Enrichment of Ore-Deposits, by S. F. Emmons, Washington, D. C.

Before adjournment, announcements were made concerning the arrangements for afternoon excursions and evening receptions, and an invitation was extended to the members and guests of the Institute to visit on Friday afternoon the Engraving and Printing Division of the U. S. Geological Survey, where all the map-work is done.

The third session opened on Thursday morning, February 22d, at 10 o'clock.

The paper of F. C. Schrader and A. H. Brooks, of Washington, D. C., on Some Notes on the Nome Gold Region of Alaska, was read by Mr. Brooks, illustrated by lantern slides, and followed by informal discussion.

The following paper was presented by the author:

Hydrographic Investigations of the United States Geological Survey in their Relation to Mining (illustrated with lantern slides), by F. H. Newell, Washington, D. C.

The fourth session opened on Friday morning, February 23d, at 10 o'clock.

Before the reading of papers, the Secretary read an invitation to the members of the Institute from Milwaukee to attend the International Mining Congress to be held there June 19th to

23d inclusive. As the Institute had no official connection with the Congress, no action was taken.

The following papers were presented by their authors:

The Clealum Iron-Ores, Washington, by George Otis Smith and Bailey Willis, Washington, D. C.

Gruson Rotating Turrets, by T. Guilford Smith, Buffalo, N. Y.

The Enrichment of Gold and Silver Veins, by Walter H. Weed, Washington, D. C.

The fifth and final session was held on Friday afternoon at 2 o'clock.

Mr. Clemens Catesby Jones, Richmond, Va., presented a paper on The Roller-Pallet System for the Manufacture of Bricks.

The annual report of the Council was presented as follows:

ANNUAL REPORT OF THE COUNCIL.

In accordance with the rules, the Council makes the following report to the Institute:

The financial statement of the Secretary and the Treasurer shows receipts from all sources for the year ending December 31, of \$31,435.60, and expenditures of \$31,551.84, not including in the receipts the cash surplus of \$7609.06 on hand January 1, 1899, or in the expenditures the investment of \$5230 in the purchase of bonds for the life-membership fund. This fund now contains, as per the auditor's report, securities of the par value of \$15,900, having a present market-value of about \$20,000, which practically covers the amount of \$100 each for the life-members now living.

Apart from the items stated, the expenditures have exceeded the receipts by \$126.21. But this result will be seen to be highly encouraging, when the special and extraordinary outlays of the year are taken into account. Among these may be named the expenses of moving the Secretary's office to its new quarters, and the suitable furnishing of the latter, the cost of which has been about \$1600 (included in the statement below under the items of the special appropriation of \$1000 for moving and equipment, and of office supplies and repairs); the payment of \$526.13 for a supply, sufficient for years to come, of "onion-

skin" paper for the folding plates inserted in papers;* the expense of sending to members throughout the world the "souvenir volume," an item which is included partly under "postage," partly under "express and freight charges," and which partly explains the increase of more than \$1000 in these two items over the figures of last year.

There were increased expenses, also, in many other departments, by reason of the increase in membership and office-work, the occupancy of new quarters at higher rent, the special outlay required in connection with the California meeting, etc. But these are not considered as exceptional. It is sufficient to say that the income of the Institute has been able to bear all but an insignificant sum of the really extraordinary expenditures above stated, amounting to more than \$2800, and that it will amply support the operations of the coming year, which have been planned on a liberal scale for the accommodation of the business of the Institute, and of members visiting its office.

The detailed statement of receipts and expenditures is as follows:

RECEIPTS.

Balance from statement,		\$7,609.06
Annual dues,	\$24,471.67	
Life membership,	1,596.96	
Binding of <i>Transactions</i> ,	2,238.65	
Sale of publications,	2,375.12	
Electrotypes,	3.60	
Interest on bonds and deposits,	747.00	
Miscellaneous,	2.60	
	<hr/>	\$31,435.60
		<hr/>
		\$39,044.66

DISBURSEMENTS.

Printing volume xxviii. of <i>Transactions</i> , . . .	\$2,718.28
" pamphlet edition of papers, . . .	3,407.29
" circulars and ballots, . . .	133.10
Binding volume xxviii. and miscellaneous volumes of <i>Transactions</i> , . . .	2,202.40
" exchanges, . . .	55.49
Engraving and electrotyping, . . .	1,150.12
Secretary's department, including clerks, stenographers, and expenses of editing and proof-reading,	8,510.50
Carried forward,	<hr/>
	\$18,277.18

* This paper is especially manufactured for the Institute, and must be ordered in considerable quantity, for that reason.

Brought forward,	\$18,277.18	
Postage, including post-office box rent,	2,055.71	
Stationery,	594.21	
Rent,	1,900.00	
Express and freight charges,	1,529.93	
Telephone,	117.45	
Telegrams, cablegrams and car-fare,	48.59	
Coal, ice and gas,	52.68	
Assistant Treasurer's department,	3,474.34	
Storage of <i>Transactions</i> ,	112.02	
Special stenographers and expenses of meetings,	1,097.40	
Office supplies and repairs,	730.88	
Insurance,	15.54	
Miscellaneous,	3.38	
Moving and equipment of new office,	1,000.00	
Onion-skin paper for plates in volume,	526.13	
Library addition,	116.40	
Purchase of Penn. R. R. 6 per cent. bonds,	5,230.00	
		<hr/>
		\$36,781.84
		<hr/>
		\$2,262.82

Since the last annual report, the office of the Institute has been moved to the fire-proof granite building of Messrs. Phelps, Dodge & Co., at 99 John Street, where a suite of four large rooms was at first secured, to accommodate the Secretary and his assistants, the Assistant Treasurer and his clerks, the mailing department, and the collection of books and files of exchanges. A fifth room has been added since, for the last-named purpose, and will be fitted up for the accommodation of members who desire to consult the volumes and files referred to.

Volume xxviii., an octavo of 1093 pages, issued and distributed during the year, is believed to be the equal of any of its predecessors in interest and value.

Two meetings were held during the year; the annual meeting in February at New York City, and the California meeting in September at San Francisco. It is not necessary here to repeat what the published proceedings of these meetings, and the papers furnished to the *Transactions* in connection with them, abundantly testify concerning their professional and social success. With regard to the California meeting in particular, the "Proceedings" bear witness to the extraordinary hospitality shown to the visiting members and guests of the Institute by the California Miners' Association and the mining companies, cities and citizens of the Pacific Coast generally.

Changes in membership have taken place during the year as follows: 2 honorary members, 196 members and 23 associates have been elected; 4 associates have become members; the deaths of 30 members and 4 associates have been reported; 50 members and 4 associates have resigned; and 43 members and 3 associates have been dropped from the roll by reason of non-payment of dues, loss of correct address, etc.* These changes are tabulated as follows:

	H. M.	F. M.	M.	A.	Totals.
At date of last report.....	9	37	2356	172	2574
Gains: By Election.....	2	.....	196	23	221
Change of Status.....	.....	.....	4	.....	4
Losses: By Resignation.....	.....	.....	50	4	54
Dropping.....	.....	.....	43	3	46
Change of Status.....	.....	.....	.....	4	4
Death.....	.....	.....	30	4	34
Total gains.....	2	.....	200	23	225
Total losses.....	.....	.....	123	15	138
Present membership.....	11	37	2433	180	2661

The list of deaths reported during the past year comprises the following: *Life Members*: William Y. Campbell, Eugene Hoefer, Nicolas E. Manzavino, J. C. Peters. *Members and Associates*: M. A. Bucke (1896), M. C. Bullock (1874), Frank Carter (1873), John S. Cary (1883), W. F. Durfee (1876), Henry Engelmann (1872), E. B. Grubb (1894), Albert Guenther (1898), E. S. Hayden (1894), E. F. Holden (1887), Alfred E. Hunt (1879), Reese James (1879), Hiram Kimball (1882), J. Cook Kingsley (1882), R. F. Lord (1882), Selden E. Marvin (1878), W. B. Middleton (1898), F. P. Miles (1877), W. E. Newberry (1885), Samuel Peters (1883), Fred. H. Smith (1890), H. S. Smith (1890), J. Harcourt Smith (1894), John H. Swoyer (1898), William N. Symington (1873), William T. Thompson (1896), J. R. Wagner (1891), Robert S. Weir (1895), James G. Wood (1893), W. Dewees Wood (1883), Clarence A. Woodford (1895).†

Concerning the list of deaths, such data as have been obtained by the Secretary are given below, in the alphabetical

* Many of these, no doubt, will be reinstated, as has been the case in former years.

† The date in parenthesis is that of election as member or associate.

order of the names. Any appropriate biographical data concerning names not here mentioned, which may be received hereafter, will be included in the next annual report.

Maurice A. Bucke was born in 1868 and died December 5, 1899, in a runaway accident at Jardine, Park county, Mont. He was graduated from the Ontario School of Practical Science in 1890, and later received the degree of Mining Engineer from the Toronto University. His first practical experience was gained on the staff of the Geological Survey of Canada, making a geographical and topographical survey of the phosphate regions of Quebec and Ontario. In May, 1892, he went to Kootenay, where he soon became prominent for his professional ability and capacity for hard work. For two years he was engineer at the Noble Five mine, and in 1895 obtained a similar appointment at the Great Slocan Star, which he filled for three years. He did not confine his labors to the Slocan, however, for during six years he managed no less than twelve properties in different sections of East and West Kootenay and in South Yale with distinguished success. In 1896 he became associated with Mr. W. Trethewey in the well-known firm of Trethewey & Bucke, Mining Engineers, of Kaslo and Vancouver. At the time of his death he was the superintendent of the Bear Gulch and the King Solomon Quartz and Placer companies, at Jardine, Park county, Mont. He was a member of the Canadian Mining Institute, and was well known and highly respected throughout Canada.

Milan C. Bullock was born in Granville, Washington county, N. Y., June 26, 1838, and brought up on a farm until eighteen years of age, when he served a miller's apprenticeship, which was eventually abandoned because of ill health. At the outbreak of the Civil War he was rejected as applicant for enlistment on account of asthma, so at twenty-four he apprenticed himself to learn the trade of machinist, where he applied himself with such determination that the end of eighteen months found him foreman of the shop. Several years were spent as journeyman, going to machine shops of all kinds from Massachusetts to Missouri, familiarizing himself with all that was best in the business, and his unvarying good nature and persistent energy always gained him friends among shopmates and employers, and rapidly advanced him to the front rank. In

1866 he entered the employ of the Steam Stone Cutter Co., of Rutland, Vt., manufacturers of the Wardwell channeler; and two years later became connected with the old Windsor Armory Co., of Windsor, Vt., then engaged in the manufacture of diamond drills and channeling machinery, where he gained the special experience afterwards of so much value to himself and to the mining industry generally. In 1870 he became superintendent of the Pennsylvania Diamond Drill Co., and put down at Phoenix Park, under the most discouraging circumstances, the first deep hole ever bored with a diamond drill. While with this company he patented a number of important improvements in diamond drills, and with Jacob Shelby invented and patented the "Long-hole" or continuous process of shaft-sinking, made famous by the eminent engineer, Gen. Henry Pleasants, who (when other mining men were calling Mr. Bullock "that crazy Yankee crank") at once recognized the advantages of his process, and had the courage to adopt his plans in sinking the two East Norwegian shafts near Pottsville, Pa., to a depth of 1685 feet, with remarkable rapidity for those days. In the fall of 1871 Mr. Bullock accepted the position of General Superintendent of the American Diamond Drill Co., of New York, and introduced the diamond drill at Hell Gate, New York harbor. He also extended its use for prospecting purposes among many mines and quarries of the Eastern States. In 1873 he superintended and built the plant used in driving the famous Lima and Oroya railroad tunnel through the Andes at a height of nearly 14,000 feet above sea level. In the summer of 1874 he was financially ruined by the failure of the American Diamond Drill Co., so he started business in Chicago the following year on a modest capital of \$600. For three years he struggled with indomitable pluck, and by perseverance and strict adherence to a high standard of excellence both in design and workmanship, he built up a large and profitable business. To diamond drills his company added the manufacture of rock-drills, air-compressors, hoists and other machinery, including the "Bullock-Corliss" engine, and the Willans high-speed engine. After a year of failing health, he died at Chicago, January 12, 1899, sincerely mourned by a large circle of personal friends, and by many an engineer whose early struggles were lightened and encouraged by his ready aid.

William Y. Campbell was born in Edinburgh about the year 1854. Left an orphan early in life, he was adopted into the family of Mr. Thomas Duff, a resident of Natal. Here he passed his youth and earnestly studied the public affairs of the colony, acquiring such a knowledge of the languages and character of the natives that he became one of the leading authorities in the colony on these and cognate subjects. In 1877 he made his first trip to England, and in the following year started business in Durban; but he soon gave up commercial pursuits, studied law, and was admitted to the Natal bar. At the request of the government he codified the laws of the colony. He was engaged in several celebrated causes, historically known as the Zulu trials, was the adviser of the late Zulu king, Cetewayo, and to the last did his utmost for the native races of South Africa. About twelve years ago Mr. Campbell left Natal for the Transvaal, settled at Johannesburg, where he occupied until his death a unique position. Though generally recognized as the representative of large Uitlander interests, and a pronounced advocate of British supremacy, he retained the confidence of the Boer leaders, and was influential in settling some of the most pressing difficulties between the Uitlanders and the Transvaal government. He became an officer of the Johannesburg Chamber of Mines, and was for some time its vice-president. He was deeply interested in the prosperity of the Witwatersrand, and the confidence in him was so general that he had access to many facts and statistics unobtainable by others. This made him a valuable contributor to the columns of the *Engineering and Mining Journal* and the pages of *The Mineral Industry*. In recent years he was greatly interested in the development of the Chartered Company territories. He was for some years managing director of the corporation known as the Gold-Fields of Matabeleland, but he resigned his position in 1896 in response to a request from the authorities to spend two or three years organizing the government of Nyassaland, a task for which he was especially fitted by his thorough knowledge of the native races, his familiarity with the various South African languages, and his high sense of equity and realization of the rights of those people. In fact, he was regarded with the greatest reverence by the Zulus of Natal, the Transvaal and the adjoining regions, and their leaders sincerely grieved to

hear of the death of "Weely," as they affectionately called him. Mr. Campbell went to London early in 1899, and in April left for Lisbon on a financial mission. Having finished his work, he was on the point of starting for Paris when he contracted small-pox, and died after a few days' illness, April 21, 1899. He was a prominent figure in Johannesburg, where he kept open house, and entertained not only friends and neighbors, but many distinguished visitors. He was an excellent orator, a clear, concise writer, and as a representative Uitlander was spokesman upon all occasions. Although never claiming to be a practiced mining engineer, he was generally recognized as an authority on mining questions, mill-management and the financial management of companies. He was a life member of the American Institute of Mining Engineers (1897), and a member or fellow of several English scientific societies.

Frank Carter was born in Pottsville, Pa., in 1834, entered the office of P. W. Sheaffer, where he studied civil and mining engineering, and remained until about 1856, when he took charge of the coal lands owned by the Philadelphia and Mahanoy Coal Co., and was actively engaged in their early development. These to-day are the most valuable in the country. In July, 1859, he located the town of Mahanoy City, laid it out into lots, and during his residence there organized and became one of the principal stockholders of the Mahanoy City Water Co. He was connected with the Philadelphia and Mahanoy Coal Co. until it sold out to the Philadelphia and Reading Coal Co. in 1872, when he was appointed land-agent for the new company, a position which he held until his death, March 22, 1899. Mr. Carter was interested in many Pottsville enterprises; was identified for a long time with the publication of the *Miners' Journal*; organized the Miners' Journal Printing Co.; was stockholder in the Pottsville Water Co. and the State Deposit Banking Co. He was an active Mason and Knight Templar, and prominent in church and Sunday-school work.

John Stockly Cary was born in Cleveland in 1867, received his technical education at the Sheffield Scientific School of Yale University and Freiberg, Saxony, taking additional courses in analytical chemistry, and established a laboratory in Chicago. In 1893 he was appointed chief chemist of the department of Mines and Mining at the Chicago World's Fair.

Later, he perfected a method for the incidental production of alcohol in the manufacture of charcoal, and continued his experiments in this line while in charge of the chemical department of the Cleveland Cliffs Iron Co., at Gladstone, Mich. His experience gained for him the position of head chemist in the American Chemical and Spirits Co., which subsequently built under his superintendence at Evansville, Ind., a large plant for the manufacture of alcohol and by-products from wood. This was practically the end of his work; for, having overtaxed his strength, he was threatened with lung trouble, forced to spend some months in Texas to recuperate, and upon his return was seized with a chill complicated with typhoid symptoms and a weak heart, and suddenly died April 9, 1899.

William Franklin Durfee, born in New Bedford, Mass., Nov. 15, 1833, took a special course of study at the Lawrence Scientific School of Harvard University, became an engineer and architect in his native town in 1853, and for five years served as City Surveyor. Sent to the State Legislature in 1861, he served as Secretary of the Military Committee and introduced a resolution requesting Congress to repeal "all laws which deprive any class of loyal subjects of the Government from bearing arms for the common defense," which is believed to have been the first formal proposition for arming negro troops. He designed a gun for naval use, and in June, 1862, went to Lake Superior to test the suitability of the iron-ores for the manufacture of steel by the method invented by William Kelley. He succeeded in producing some steel ingots from which, on May 25, 1865, were rolled the first steel rails made in this country. He established at Wyandotte, Mich., the first analytical laboratory built as an adjunct to steel works in the United States to study the Bessemer process and the use of the regenerative furnace. He received a medal at the Centennial Exposition in Philadelphia, 1876, and was one of the judges of machine tools for wood-, iron- and stone-working. At Ansonia, Conn., he built the first successful furnaces for refining copper by the use of gaseous fuel. In 1886 he became general manager of a company controlling patents for the production of wrought-iron and steel castings. His death occurred at Middletown, N. Y., Nov. 14, 1899. He became a member of the Institute in 1876, presented the following papers: "An Account of a Chemical

Laboratory erected at Wyandotte, Michigan, in the year 1863" (*Trans.*, xii., 223); and "A Vacuum-pump and Table-blow-pipe" (*Trans.*, xiii., 279); and was a frequent contributor to discussions on Bessemer plants and the manufacture of iron and steel.

Henry Engelmann, who died at La Salle, Ill., March 30, 1899, took a very prominent part in the development of the zinc-smelting industry of the United States. He was for over 26 years in charge of a department of one of our most important zinc works, and no one could show a longer experience or a wider knowledge of the work. He was born at Frankfort, Germany, October 1, 1831, and after graduating from the Gymnasium of Creuznach and the University of Berlin, studied in the mining school at Freiberg, Saxony. After a year spent in visiting and studying various mines and metallurgical works, he came to the United States in 1856, and lived for awhile in St. Louis. He traveled through Missouri and participated in General Simpson's expedition to the Southwest. In 1858 he accompanied Gen. Albert Sidney Johnston's expedition to Utah, and after his return was engaged in geological work at Washington. Early in 1861 he left, and, after a visit to the oil regions, went to Illinois, where he became connected with the State Geological Survey, and held the position of State Geologist for four years. In 1869 he was employed by the Matthiesen & Hegeler Zinc Co., at La Salle, Ill., and remained in that company, with the exception of two years spent in Utah studying coal-deposits and manufacturing coke, in the capacity of superintendent of the ore department and general consulting engineer until his death. He was a careful student, acquired a very thorough knowledge of the zinc industry, and made many improvements in the metallurgy of the metal. He was a highly esteemed member of the Institute since 1872, and contributed the following valuable papers: "The Brown Coals of Utah and Adjoining Territories" (*Trans.*, iv., 298); and "The Utsch Automatic Jig" (*Trans.*, ii., 81).

Edward B. Grubb, who died of typhoid fever in Philadelphia, January 8, 1899, was connected for the greater part of his professional career with the Sheridan Iron Works Co., at Sheridan, Pa., where, through industry and personal merit, he rose from a position of minor importance to become the Treasurer of the company.

Edward Simeon Hayden, born in Waterbury, Conn., October 20, 1851, began his career as a bookkeeper in the Waterbury National Bank in 1869, and was elected Secretary and Treasurer of Holmes, Booth & Hayden ten years later. Having devoted himself to the study of the metallurgy of copper he became connected with the Bridgeport Copper Co. in the fall of 1886, and then put in practice the results of his studies and experiments. He was one of the promoters of the Baltimore Electric Refining Co., organized in 1891 for the express purpose of using his process for the treatment of metals by electrolysis, an invention patented in this country and abroad. This process is now in use at some of the largest copper refining works in this country.

Eugene Hoefer, who died April 16, 1899, at Lydenburg, in the Transvaal, graduated from the University of California, and was well known on the Pacific coast before he went to South Africa. He was prominent as a mining engineer and metallurgist in the Transvaal, and for several years past was manager of the Lydenburg Estates.

Edward F. Holden was born at Charlotte, near Rochester, N. Y., Sept. 16, 1826, and died on Christmas day, 1899, in Syracuse, where he had spent nearly half of a useful life. He started his career as a carpenter and a school teacher, but was attracted to the industrial field, and soon associated himself with his uncle in the general forwarding business of the port of Charlotte and the New York Central railroad, while they conducted at the same time a dry-goods and grocery house. After two years' residence in Rochester he moved to Syracuse in 1869 and became agent for the Delaware, Lackawanna and Western Railroad Co. for the sale of its coal in Syracuse and the territory east and west on the canal and railroads, a position which he held until his death, and for a number of years he was vice-president and general manager of the Syracuse and Binghamton railroad. Though not a professional man he was an earnest reader of scientific works, and an associate member of the Institute for twelve years. He was well-informed in astronomy, geology, mathematics, chemistry, physiology, literature and art, and chief among the generous gifts and benefactions which he made regularly, unostentatiously and voluntarily to charitable, religious and educational institutions, was a fully

equipped observatory presented by him to the University of Syracuse in memory of his son.

Alfred Ephraim Hunt, born in East Douglass, Mass., March 31, 1855, passed two years at Harvard College after graduating from the Roxbury High School in 1870. Declining an appointment as cadet to West Point, he took a course at the Massachusetts Institute of Technology, where he received a degree from the Department of Metallurgy and Mining Engineering in 1876. For some time following graduation he was engaged with the United States Geological Survey and private corps making topographical and railroad surveys in the West; then he found employment with the Bay State Iron Works in South Boston, where the second open-hearth steel furnace in America was erected. At the suggestion of the manager of the firm he was sent to Michigan to explore for iron-ore, and upon the analysis of his specimens was written the report of the Michigamme mines, the first and finest strikes in the wonderful iron-fields of northern Michigan and Wisconsin. From 1877 to 1879 he was manager and chemist at the Nashua, N. H., open-hearth steel works. Then he went to Pittsburgh as superintendent and chemist with Park Bros. & Co., Limited, but resigned in 1882, and with George H. Clapp, of that company, formed the firm of Hunt & Clapp. They became the chemists of the Pittsburgh Testing Laboratory which had been established a short time previous by William Kent and W. F. Zimmerman, for the physical and chemical testing of materials and the inspection of iron and steel structures; and in 1885 they bought out the original owners and became the sole proprietors. This firm has inspected the greater number of the important metal structures erected during the last fifteen years, including Mississippi and Missouri river bridges, and the Hudson river bridge at Poughkeepsie. At the end of ten years the business had grown to such proportions that a stock company was formed and purchased it of Hunt & Clapp for \$75,000. The manufacture of aluminum was the fourth important enterprise in which Capt. Hunt was interested. In 1888 he organized the Pittsburgh Reduction Co. to manufacture aluminum under the patents of Charles M. Hall, and thenceforth most of his attention was given to this industry. The admirable design and structure of the new works at Niagara Falls, the steady

reduction in the cost of manufacture, the growth of the industry and the widespread use of the metal, all bear witness to his energy, judgment, skill and enterprise. Capt. Hunt derived his title from a twelve years' command of Battery B, National Guard of Pennsylvania. It was mustered into the United States service during the war with Spain, and went upon the expedition to Puerto Rico, where he contracted the fever which eventually caused his death in Philadelphia, April 26, 1899. Capt. Hunt gained high reputation as an authority on engineering, metallurgy and chemical analysis, and was frequently summoned to the courts to give expert testimony. Scientific and engineering societies in this country and Great Britain have recognized his services by conferring upon him official positions in their respective organizations. He received the Norman gold medal from the American Society of Civil Engineers, of which he was a member, for the best paper on engineering at the famous Chicago competition in 1894. He was a member of the Institute since 1879, and also of the following societies: American Association for the Advancement of Science, American Society of Civil Engineers, American Society of Mechanical Engineers, American Chemical Society, the Iron and Steel Institute, and the Institute of Engineers of Great Britain. He was the author of many valuable papers on scientific subjects, and contributed the following to the *Transactions* of the Institute: "Soft Steel for Boiler-Plates" (*Trans.*, xiv., 826); "Some Notes and Tests of an Open-Hearth Steel Charge made for Boiler-Plates" (*Trans.*, xii., 311); "The Colorimetric Determination of Carbon in Steels" (*Trans.*, xii., 303); "The Estimation of Manganese in Iron and Steel by the Color-Method" (*Trans.*, xv., 104); "A Note upon a Modification of the Refining Process used by the Carbon Iron Company" (*Trans.*, xvii., 678); "Some Recent Improvements in Open-Hearth Steel Practice" (*Trans.*, xvi., 693); "The Tests and Requirements of Structural Wrought-Iron and Steel" (*Trans.*, xx., 677); (in collaboration with George H. Clapp) "The Inspection of Materials of Construction in the United States" (*Trans.*, xix., 911), and "The Impurities of Water" (*Trans.*, xvii., 338); (in collaboration with John W. Langley and Charles M. Hall) "The Properties of Aluminum, with Some Information Relating to the Metal" (*Trans.*, xviii., 528);

"Biographical Notice of Joseph D. Weeks" (*Trans.*, xxvii., 231); and frequently took part in the discussions of other papers.

Hiram Kimball was born at Randolph, Vt., in 1845. He evinced a taste for mechanics at an early age, and, after a technical education in Philadelphia, was employed as engineer by A. L. Holley in developing the Bessemer process of steel-making in this country. He was also engaged at one time at the Edgar Thomson steel works. For aid in business affairs he took a partial course of law at the Columbia Law School, New York City, and was admitted to the Michigan bar in 1880. He was the inventor of a number of important devices which brought him a large fortune; among which may be mentioned a rail-joint and a pressed, wrought-iron turn-buckle, which was manufactured under his patents and supervision by the Cleveland City Forge and Iron Co., Cleveland, Ohio. He formed also the Chapman Jack Screw Co., of which he was president, and the Butler Draw-Bar Attachment Co., both of which were affiliated with the above-mentioned company. Mr. Kimball was also a member of the Chamber of Commerce, largely interested in the city street railway companies and other local enterprises; was a prominent Mason and Knight Templar, and held membership in the American Society of Civil Engineers and the Institute (1882). He died in Cleveland, Ohio, March 9, 1899, of Bright's disease.

Russell Farham Lord was born at Honesdale, Pa., October 1, 1837, and educated at the Sheffield Scientific School of Yale University. For a number of years he served the Delaware and Hudson Canal Co. as paymaster and chief engineer under his father, and then succeeded him as general manager. He was commissioned Brigadier-General of Volunteers by the Governor of Pennsylvania, served throughout the Civil War, and at its close went to Colorado, where he was engaged in mining and the practical study of mines, changing this, three years later, for the coal business. In 1871 he was sent to California by English capitalists to examine coal and farm lands, and until 1878 was chief engineer and general superintendent of the Brentwood Coal Co., the "Rancho de los Meganos" and other lands in the San Joaquin valley. During the development of these lands he defined the series of coal, afterwards named by Clar-

ence King, of U. S. Geological Survey, "the Lord series." Owing to litigation and to the failure of the company in London, the coal was not put on the market. From 1879 to 1885 he was employed as mine superintendent in various parts of Colorado. In the spring of 1886, while visiting his sons in Guatemala, Central America, he was called to Salvador to appraise a railroad and its appurtenances, and adjust a settlement between British bondholders, contractor and the new government. The adjustment was satisfactorily made, and Mr. Lord was appointed chief engineer to the government, a position which he resigned in 1889. For a year thereafter he was superintendent of construction of public buildings in the Quartermaster's Department, U. S. Army, engaged principally on work at Fort Wadsworth, Fort Hamilton and Governor's Island. In 1892 he was sent to Ecuador to develop the mining property of the Playa de Oro Mining Co. He returned five years later, owing to failing health. At the time of his death, which occurred July 12, 1899, he was planning to sail for Ecuador to examine, as consulting engineer, the work done in his absence.

Nicolas E. Manzavino, a native of the island of Cephalonia, was born in Smyrna, February 25, 1856, and died at the age of 39, on August 29, 1895. Left fatherless at an early age, he was educated under the kind influence of his tutor, Denis Marcopulo, of Smyrna. Graduating with honorable mention in mathematics from the Evangelical school of Smyrna in 1873, and after some preparatory studies in Athens, he entered the School of Mines in Freiberg, Saxony, in 1874, and spent five years studying mining and metallurgy, receiving his diploma as Mining Engineer in 1879. Upon his return to Athens, he entered the service of Mr. Serpieri, who employed him partly at Laurium and partly in the adjacent islands, where he owned mines. The following two or three years were passed in the service of the "Society of the Mines of Laurium," which gave him general direction over the work of the mines of Balia-karaïdin in Mysia, Asia Minor. These were the famous mines mentioned by Strabo. He worked these mines until his death, and by his administration became known as a man of talent and great capacity. He was obliged to contend, in this uncivilized corner of Turkey, with men ignorant of duty and dis-

cipline, and he had about a thousand under his orders; with the infinite claims of subaltern employes of the government, men of an insatiable appetite, whose duty lay in putting on the pressure to extort money; with the difficulties created by the absolute prohibition of the importation of dynamite, in place of which the government forced him to buy powder of an inferior quality at exorbitant and onerous prices. He was obliged to contend, also, and most serious of all, against the constant decline in the price of the metals taken from the mines of which he had charge. Considering all these difficulties, it is clear that only a man of force as savant and manager could continue to develop the mines without stopping the work, except provisionally. Unfortunately he was not permitted to live long enough to see his work prosper by the impetus and good organization which he had given to his undertakings. His death caused great sorrow among his rough workmen, and among all those in general who were under his orders; for he had managed to make himself loved like a father. By imposing an iron discipline he always showed himself just and good in his severity. His superiors reposed inalterable esteem and confidence in him. In June, 1895, about two months before his death, he was made corresponding member of the State Institute of Geology of Vienna, for services rendered to that body in enlarging their collection of fossils. He was a life member of the American Institute of Mining Engineers since 1890.

William B. Middleton was born in Philadelphia, September 17, 1849, and began his professional career with the Phoenix Iron Co., of Phoenixville, Pa. He was subsequently connected with the Edge Moor Iron Works, of Edge Moor, near Wilmington, Del.; the Penn Iron Co., of Lancaster, Pa.; the Pennsylvania Bolt and Nut Co., of Lebanon, Pa., of which he became president, and the Allison Manufacturing Co., of Philadelphia. In the summer of 1896 he was made general manager of the Taylor Iron and Steel Co., High Bridge, N. J., a position which he held at the time of his death, March 8, 1899.

Frederic Phumb Miles was born in Goshen, Conn., June 3, 1854, educated at the Sheffield Scientific School of Yale University, where he graduated in 1876. His delicate health forced him to abandon his intention of taking a special course of study in chemistry abroad, so he joined his father and brother in the

iron business at the Copake Iron Works, Copake, N. Y. In 1881 he moved to Lakeville, Conn., where he resided until his death, February 19, 1897.

Wolcott Ely Newberry, son of the late Professor John S. Newberry, of Columbia College, New York City, was born in Cleveland, Ohio, September 26, 1862, and graduated in 1884 at Columbia College School of Mines. He showed marked ability in his profession, for he was at once put in charge of a smelter in Arizona under the Casa Grande Copper Mining Co., and a couple of years afterwards became superintendent of the Canama Mining Co., Sonora, Mexico. Between 1887 and 1893 he was most active in the mining industry of Colorado and Utah, acting as manager of the following companies: In Aspen, Colo., from 1886-1890, Enterprise Mining Co.; 1887, Aspen Mining and Smelting Co.; 1887-1890, Argentum Mining Co.; 1889-1892, Bimetallic Mining Co. and Aspen Contact Mining Co.; in Mercur, Utah, 1892-1893, Viking Gold Mining Co.; in Cripple Creek, Colo., 1892-1893, Isabella Gold Mining Co. and Zenobia Gold Mining Co. His arduous labors caused a nervous breakdown which forced him to give up work for the time, and seek rest and strength in California in the winter of 1893-1894. The famous Cripple Creek strike occurred during his absence, and at the time of the riot a splendid tribute was paid him by the miners. "If the 'Colonel' (his sobriquet among the men) had only been here, we never would have struck!" In 1896 he became manager of the South American Development Co., Zaruma, Ecuador, a position which he was filling when his sudden and untimely death at Newport, R. I., June 12, 1898, cut short a promising career. Mr. Newberry became a member of the Institute in 1885, and contributed "Notes on the Geology of the Aspen Mining District" (*Trans.*, xviii., 273).

Samuel Peters was born in England in 1847, and came to America in 1870. For a number of years he was chemist for the Bay State Iron Works, in Boston, Mass., and later chief chemist for the Burden Iron Works, Troy, N. Y. After a few months in business as chemist in Nashua, N. H., he accepted the position of superintendent of the Portland Rolling Mills, of Portland, Maine. He retained this position from 1882 until the spring of 1898, when he became connected with the Pitts-

burgh Reduction Co., leaving their employ after a year and a half to accept the position of constructing engineer with Jones & Laughlins, of Pittsburgh, Pa. He had been in their employ only four days, and was taking measurements when he fell from a trestle and sustained a fracture of the skull, from which he died September 28, 1899.

John Henry Swoyer was born in Pennsylvania in 1872, and resided in Scranton until the death of his father in 1887, when he went to Germany, and eventually graduated as mining engineer from the School of Mines at Freiberg, Saxony. Upon his return he went to Mexico, where he was engaged in professional work at the time of his death, August 12, 1899.

William Newton Symington was born at Washington Arsenal, D. C., June 10, 1841, and received his professional education at Lafayette College, Easton, Pa.; Rensselaer Polytechnic Institute, Troy, N. Y., and afterwards studied at Göttingen and Freiberg, Germany, and the Ecole des Mines, Paris. During the Civil War he enlisted in the Confederate Army, was captured, imprisoned in Fort Lafayette, N. Y., and Fort Warren, Mass., exchanged, and again entered the Confederate service in the Nitre and Mining Bureau. He was afterwards steadily employed as mining engineer and metallurgist; for a long time with the Atlantic White Lead Co., then with the National Lead Co. until 1891. Then he retired to his farm in North Carolina, engaging only in consulting practice until his death, December 24, 1899. He was one of the pioneers in the development of American metallurgical industries, and one of the early members of the Institute, which he joined in 1873.

William T. Thompson was born in Boston, April 5, 1857, and was educated at the Massachusetts Institute of Technology. After graduation he spent several years studying practical mining in northern Mexico and Arizona. He proceeded through California to British Columbia, and in 1880 was employed under Andrew Onderdonk in the construction of the Canadian Pacific railway along Fraser and Thompson rivers. In 1885, at the outbreak of the placer excitement, he went to Granite Creek, and engaged in placer work and mercantile pursuits. He was manager of the Tulameen Hydraulic Co.'s operations on the Tulameen river from 1891 to 1892, when he went to Fairview, B. C., and was for some time connected with the

Stratheyre Mining Co. From 1895 until the time of his death, June 16, 1899, he turned his attention exclusively to quartz mining in the Boundary creek and Kettle river portion of Southern Yale, where his great activity and remarkable vitality enabled him to gain a valuable detailed knowledge of a large area. That portion of southern British Columbia owes much of its present prosperity to Mr. Thompson's efforts towards the introduction of capital.

John R. Wagner was born at Bethlehem, Pa., in 1860. His early educational advantages were limited, but after serving an apprenticeship in a machine shop he entered Lehigh University, where, by dint of pluck and determination, he graduated with honors as a mechanical engineer in 1885. He became secretary and confidential assistant to the late Eckley B. Coxe, and was put in charge of the fine private library and experimental physical-chemical and mechanical testing laboratory. In 1895 he became superintendent of motive power of the Delaware, Susquehanna and Schuylkill railroad, and in 1898 was made superintendent of the Coxe Manufacturing Co. and machinery department. He was principal of the Mining and Mechanical Institute of Freeland, and much of the success of this creditable institution was due to his management. His experience gained in the testing laboratory of Mr. Coxe fitted him as an expert in experimental work upon fuels and the preparation of coal. He died at Drifton, Pa., January 21, 1899.

W. Dewees Wood, the grandson of James Wood who founded the Schuylkill Iron Works at Conshohocken, Pa., was born at Philadelphia in 1825. As a young man, and with only a common school education, he managed one of his father's sheet-iron mills. He established in 1851 with his father-in-law, Richard B. Gilpin, the original plant of the McKeesport Iron Works at McKeesport, Pa., for the manufacture of planished sheet-iron by a process patented by Mr. Wood. In 1862 he formed the partnership of Wood & Lukens, and manufactured American-Russia and black sheets. In 1878 the firm of W. D. Wood & Co., Limited, was formed, and in 1888 incorporated under the name of W. Dewees Wood Co., with Mr. Wood as president. The small plant built in 1851 has become one of the largest in the Monongahela valley. Mr. Wood also owned the Wells-ville Plate and Sheet-Iron Co. of Wellsville, Ohio, and was in-

terested in glass and gas enterprises, selling out the McKeesport illuminating gas works in 1897 to the United Gas and Coke Co. His death occurred at Pittsburgh, January 2, 1899.

The Scrutineers reported that the following officers had been elected :

PRESIDENT.

JAMES DOUGLAS, New York City.

VICE-PRESIDENTS.

(To serve two years.)

DAVID T. DAY, Washington, D. C.
J. B. RANDOL, New York City.
W. C. RALSTON, San Francisco, Cal

MANAGERS.

(To serve three years.)

D. H. BACON, Soudan, Minn.
E. V. D'INVILLIERS, Philadelphia, Pa.
WILLIAM KENT, Passaic, N. J.

TREASURER.

THEODORE D. RAND, Philadelphia, Pa.

SECRETARY.

ROSSITER W. RAYMOND, New York City.

After the passage of a resolution instructing the Secretary to acknowledge by suitable official letters the courtesies shown to the Institute by individuals, firms, corporations and government departments, not forgetting the efficient and highly successful labors of the Local Committee, the meeting was adjourned.

PAPERS PRESENTED IN PRINTED FORM AND NOT INCLUDED
ABOVE.

Gold-Ores of the Black Hills, South Dakota, by H. M. Chance, Philadelphia, Pa.

A New Method for Working Deep Coal-Beds, by H. M. Chance, Philadelphia, Pa.

A Device for Sampling Pig-Iron, by Porter W. Shimer, Easton, Pa.

A Peculiar Siliceous Efflorescence upon Pig-Iron, by B. F. Fackenthal, Jr., Riegelsville, Pa.

Note on the Plate-Amalgamation of Gold and Silver, by E. A. H. Tays, Sinaloa, Mexico.

PAPERS PRESENTED IN MANUSCRIPT, OR READ BY TITLE, FOR
SUBSEQUENT PUBLICATION AND DISCUSSION.

Biographical Notice of Thomas Egleston, Ph.D., LL.D., by George F. Kunz, New York City.

Metasomatic Processes in Fissure-Veins, by Waldemar Lindgren, Washington, D. C.

A Peculiar Clastic Dike near Ouray, Colorado, and its Associated Deposit of Silver-Ore, by F. L. Ransome, Washington, D. C.

The Occurrence of Platinum in the United States, by Dr. David T. Day, Washington, D. C.

Notes on the Gold-Mines of Zaruma, Ecuador, by J. R. Finlay, Colorado Springs, Colorado.

The Cripple Creek Volcano, by T. A. Rickard, Denver, Colo.

The Coal-Fields Around Tsê Chou, Shansi, China, by N. F. Drake, Tientsin, China.

An Examination of the Ores of the Republic Gold-Mine, Washington, by Dr. Thomas M. Chatard and Cabell Whitehead, Washington, D. C.

Geological Relations of the Iron-Ores in the Cartersville District, Georgia, by C. Willard Hayes, Washington, D. C.

Distribution of the World's Production of Pig-Iron, by John Birkinbine, Philadelphia, Pa.

Hydraulic Pumping-Plant on the Snake River, Idaho, for Power, Irrigation and the Treatment of Gold Sands, by John Birkinbine, Philadelphia, Pa.

The Assay of Copper-Materials for Gold and Silver, by L. D. Godshall, Spokane, Wash.

Further Notes on the Bertrand-Thiel Process, by Joseph Hartshorne, Stowe, Pa.

The Progress of Mineralogy in 1899, by S. Harbert Hamilton and James R. Withrow, Philadelphia, Pa.*

Further Notes on Elimination of Impurities from Copper in Refining and Converting, by Edward Keller, Baltimore, Md.

Types of Copper-Deposits in the Southern United States, by W. H. Weed, Washington, D. C.

* Published by the Institute as *Bulletin* II.

MEMBERS AND ASSOCIATES ELECTED.

The following persons were elected members or associates during the sessions of the meeting :

MEMBERS.

B. N. Bailey,	Philadelphia, Pa.
Robert Camm,	Ansted, W. Va.
Rolla C. Carpenter,	Ithaca, N. Y.
Charles A. Chase,	Telluride, Colo.
Joseph K. Choate, Jr.,	Fierro, New Mexico.
Charles Alexander Clarke,	Loope, Cal.
George Ernest Collins,	Nacoochee, Ga.
Frank Coyne,	New York City.
Charles Henry Davis,	New York City.
Arthur Henry Eyles,	Philadelphia, Pa.
A. D. Foote,	Grass Valley, Cal.
Edward J. Fowler,	Campo Seco, Cal.
Leon Stacey Griswold,	Dorchester, Mass.
Julian Green Hearne,	Wheeling, W. Va.
Dana C. Irish,	Mapimi, Durango, Mexico.
Wilbur C. Knight,	Laramie, Wyoming.
Waldemar Lindgren,	Washington, D. C.
Robert Linton,	Belle Vernon, Pa.
Edgar Messer,	London, England.
John Forsyth Miller,	Trail, B. C., Canada.
Edward A. Paterson,	Nelson, B. C., Canada.
Otto Frederick Pattberg,	Jersey City, N. J.
Frank Emory Pearce,	Pine, Oregon.
Clarence Bardwell Peck,	Plainfield, N. J.
J. H. Powell,	London, England.
William E. Renshaw,	Idaho Springs, Colo.
Frank W. Royer,	Silverton, Colo.
Herbert Kilburn Scott,	Minas, Brazil.
J. W. Shook,	Birmingham, Ala.
Henry Shriver,	Mount Savage, Md.
Lewis G. Stevenson,	Pinos Altos, New Mexico.
Lucius S. Storrs,	St. Paul, Minn.
Polk Tarwater,	Rockwood, Tenn.
Frank Taunton,	Pietermaritzburg, Natal, South Africa.
Ernest A. Thies,	Haile Gold Mine, P. O., S. C.
Albert W. Tucker,	Gold Hill, N. C.
Thomas F. Walsh,	Washington, D. C.
Charles de Wendel,	Hayange, Lorraine.
Cyril Wigmore,	Los Angeles, Cal.

ASSOCIATES.

E. V. Badwell,	Victoria, B. C., Canada.
Ludwig Seeger,	New York City.
William Murdock Wiley,	Gold Hill, N. C.

ASSOCIATES MADE MEMBERS.

T. B. Brooks,	.	.	.	Newburgh, N. Y
James Moore Elmer,	.	.	.	Baker City, Ore.
Frank M. Zeller,	.	.	.	Philadelphia, Pa

EXCURSIONS AND ENTERTAINMENTS.

On Wednesday afternoon a large party of the members, with their guests and ladies, visited the Washington Navy Yard by special arrangement, and were received by Rear Admiral McCormick, the Commandant, and a staff of officers, who conducted them through the gunshops, the model tank-house and repair shops, explaining the mechanism of the rapid-fire guns, and the operation of shrinking-on the various jackets of the big pieces of ordnance. Others visited the Washington Monument, Smithsonian Institution, National Museum, and Bureau of Engraving and Printing.

In the evening the Trustees of the Corcoran Art Gallery and the Washington Academy of Arts and Sciences tendered a brilliant reception to the members and guests in the new Art Gallery.

On Thursday afternoon at 1.45 the entire party left by the steamer Macalester on a special excursion to Mt. Vernon, and spent a beautiful afternoon visiting the tomb and country mansion of George Washington. Photographic groups were taken of the party on the lawn.

On Thursday evening the new building of the Library of Congress was thrown open to inspection, and the guests were conducted through the various departments by the Librarian and his assistants. The corridors, reading- and delivery-rooms, stack-rooms and basement, with the complicated machinery for conveying books from stack to delivery-desk, and by underground conduit to the Capitol building, a quarter of a mile distant, were visited and explained.

On Friday afternoon at 1 o'clock the members and guests were received by President McKinley at the White House; and at 3 o'clock a party visited the Division of Map-printing at the office of the Geological Survey, where they examined the processes of map-making, engraving, lithographic work and color-printing in full operation.

On Friday evening a brilliant subscription-banquet was held in the banquet-hall of the Arlington Hotel, at which about one hundred guests were present. The walls and tables were profusely decorated with flowers, vines and tiny electric lamps, while a huge American flag, formed of colored electric lights, adorned the wall behind the president's seat. The usual toasts and speeches followed.

During the visit of the Institute the courtesies of the Cosmos Club were extended to the members.

MEMBERS, ASSOCIATES AND GUESTS REGISTERED.

The following persons were registered at headquarters :

Taylor Allderdice.
Charles Bailey.
George R. Bentley.
John Birkinbine.
M. E. Campbell.
J. A. Capp.
H. S. Chamberlain.
E. H. Chapman.
Thomas M. Chatard.
Albert H. Chester.
Joseph K. Clark.
W. A. Clark.
Edgar S. Cook.
W. M. Courtis.
Thomas Clark Culver.
N. H. Darton.
David T. Day.
F. O. Dewey, Jr.
Frederic P. Dewey.
James Douglas.
Charles B. Dudley.
Uriah Dudley.
W. W. Duffield.
Theodore Dwight.
S. F. Emmons.
W. E. C. Eustis.
Thomas M. Eynon.
B. F. Fackenthal, Jr.
John Fritz.
H. D. Gamble.
William Glenn.
Arnold Hague.
C. Willard Hayes.
G. C. Hewett.
Henry D. Hibbard.
C. T. Holbrook.
J. A. Holmes.

Austin S. Horn.
H. M. Howe.
Robert W. Hunt.
J. P. Jackson.
Alfred E. Jessup.
J. E. Johnson.
Clemens C. Jones.
Horatio C. King.
G. F. Knapp.
F. H. Knight.
B. B. Lawrence.
A. R. Ledoux.
Andrew E. Lee.
Horace Lee.
I. P. Lohme.
W. Lindgren.
Jawood Lukens.
E. M. McIlvain.
Charles A. Matcham.
W. F. Mattes.
S. F. Morris.
Charles E. Munroe.
H. B. C. Nitze.
George Ormrod.
Logan W. Page.
W. N. Page.
Park Painter.
E. W. Parker.
John S. Pechin.
H. C. Perkins.
William B. Phillips.
Josiah Pierce, Jr.
A. E. Piorkowski.
D. O. Purington.
Theodore D. Rand.
J. D. Randol.
Alfred Raymond.

R. W. Raymond.	F. McM. Stanton.
Arnold K. Reese.	J. R. Stanton.
Robert E. Richards.	George Steiger.
Thomas M. Righter.	H. H. Stoek.
Thomas Robins, Jr.	J. F. Tarwater.
C. S. Robinson.	A. Thies.
T. W. Robinson.	H. G. Torrey.
W. S. Russel.	David Townsend.
F. Z. Schellenberg.	E. D. Treadwell.
H. J. Seaman.	H. W. Turner.
Horace See.	Charles D. Walcott.
A. W. Sheaffer	Walter H. Weed.
Clement G. Smith.	Cabell Whitehead.
J. Bennett Smith.	W. H. Wiley.
Oberlin Smith.	John Wilkes.
T. Guilford Smith.	William Wilkins.
J. C. Smock.	Oliver Williams.
George E. Somers.	Bailey Wilhs.
E. G. Spilsbury.	Frank M. Zeller.

To this total of 112 should be added the number of ladies accompanying members, which will increase the number to 180. But on this occasion, no doubt, as at previous meetings, many members and guests, not staying at the Arlington Hotel, failed to register their names.

Proceedings of the Seventy-Ninth Meeting, Canada, Nova Scotia and Newfoundland, August, 1900.

General Committee.—James F. Lewis, Sherbrooke, Que., *Chairman*: Eugene Coste, Toronto, Ont.; A. Marshall Hay, Rat Portage, Ont.; C. H. Carriere, Quebec, Que.; Hiram Donkin, Sydney, C. B.; W. L. Libbey, North Brookfield, N. S.; Henry S. Poole, Stellarton, N. S.; Charles Fergie, Westville, N. S.; A. G. McNulty, Waverly, N. S.

General Secretary.—B. T. A. Bell, Ottawa, Ont.

Headquarters.—Rosslyn Rink, Sydney, C. B.; Halifax Hotel, Halifax, N. S.

THE first session, a joint meeting with the Canadian Mining Institute and the Mining Society of Nova Scotia, was held in the Rosslyn Rink, Sydney, Cape Breton, on Tuesday, August 21, 1900, at 8 p.m.

In the absence of President Fowler, of the Canadian Mining Institute, Mr. Charles Fergie, Senior Vice-President, called the meeting to order and introduced Mr. Crowe, Mayor of Sydney, who welcomed the visitors to that town.

Mr. W. L. Libbey, President of the Mining Society of Nova Scotia, also made a short address of welcome on behalf of that society. President Douglas responded for the Institute to these addresses, and, upon his request, Dr. Raymond, Secretary of the American Institute of Mining Engineers, and Mr. B. T. A. Bell, Secretary of the Canadian Mining Institute, made further remarks.

Mr. John S. McLennan, of Sydney, gave a brief account of early coal-mining in Cape Breton; and Mr. Charles S. Hinchman, of Philadelphia, voiced the American opinion on the remarkable steel-plant visited that day. Informal discussion followed, in which many participated.

The second session was held at the Halifax Hotel, Halifax, Nova Scotia, on Monday, August 27, at 10 A.M.

The Secretary presented brief summaries of the following papers:

Deep-Level Shafts on the Witwatersrand, with Remarks on a Method of Working the Greatest Number of Deep-Level Mines with the Fewest Possible Shafts, by Thomas H. Leggett, Johannesburg, South Africa.

Notes on the Compressed-Air Haulage-Plant at No. 6 Colliery of the Susquehanna Coal Company, Glen Lyon, Pennsylvania, by J. H. Bowden, Wilkesbarre, Pa.

The Testing of Winding-Ropes in the Province of Anhalt, Germany, by Frank H. Probert, London, England.

Informal discussion of these papers followed.

Mr. George W. Stuart, of Truro, N. S., gave an account of gold-mining in Nova Scotia.*

The following papers were presented in printed form:

Signal-Device for Mines, by Charles S. Herzig, Virginia, Minn.

The Oil-Bearing Shales of the Coast of Brazil, by Prof. J. C. Branner, Stanford University, Cal.

The Properties of Brass Made from Copper Containing Sub-

* Not published in these *Transactions*, Mr. Stuart having prepared it as an article for the *N. Y. Eng. and Min. Jour.*, in which it subsequently appeared, Sept. 15, 1900.

Oxide, with Observations of the Effect of Oxygen on Copper, by Erwin S. Sperry, Bridgeport, Conn.

The Colorimetric Assay of Copper, by J. D. Audley Smith, Clifton, Ariz.

The Protection of Blast-Furnace Linings, by S. S. Hartranft, Buffalo, N. Y.

Coal-Outcrops, by Charles Catlett, Staunton, Va.

The following papers were read by title :

A Mining Survey, by J. F. Wilkinson, San Francisco, Cal.

The Explosion at the Red-Ash Colliery, Fayette County, West Virginia, by William N. Page, Ansted, W. Va.

An Occurrence of Limburgite in the Cripple Creek District, by E. A. Stevens, Victor, Colo.

The Iron-Mines of Hartville, Wyoming, by Dr. H. M. Chance, Philadelphia, Pa.

The Indicator Vein, Ballarat, Australia, by T. A. Rickard, Denver, Colo.

The Telluride-Ores of Cripple Creek and Kalgoorlie, by T. A. Rickard, Denver, Colo.

A Method for Obtaining the Volume of Small Drifts and Working-Places, by Charles S. Herzig, Virginia, Minn.

The Influence of Silicon and Sulphur on the Condition of Carbon in Cast-Iron, by Prof. H. M. Howe, New York City.

Pyritic Smelting in the Black Hills, by Prof. Franklin R. Carpenter, Denver, Colo.

The Micro-Structure and Physical Properties of Cast-Iron, as Affected by Heat-Treatment, Especially in the Manufacture of Malleable Cast-Iron, by A. T. Child, Perth Amboy, N. J., and W. P. Heineken, New York City.

Experiments Regarding the Influence of Silica on the Loss of Silver in Scorification, by Lester Strauss, New York City.

Notes on Mine-Surveying Instruments, with Special Reference to Mr. Dunbar D. Scott's Paper on their Evolution, and its Discussion, by Benjamin S. Lyman, Philadelphia, Pa.

The Geology and Vein-Phenomena of Arizona, by Theo. B. Comstock, Los Angeles, Cal.

MEMBERS AND ASSOCIATES ELECTED.

The following persons were elected members or associates :*

MEMBERS.

Cleveland Abbe, Jr., . . .	North Carolina.
R. G. S. Anthony, . . .	Coolgardie, West Australia.
Frank Ashton, . . .	Chihuahua, Mexico.
Ralph Baggaley, . . .	Pittsburg, Pa.
James B. Bailey, . . .	Harrisburg, Pa.
Hugh A. Bain, . . .	New York, N. Y.
Franklin Ballou, . . .	Leadville, Colo.
Edwin G. Banks, . . .	Auckland, New Zealand.
Thomas H. Barclay, . . .	Barclay, Ariz.
Joseph F. Batchelder, . . .	Portland, Oregon.
Wray Annin Bentley, . . .	Brooklyn, N. Y.
H. von Borbely, . . .	Salgo-Tarjan, Hungary.
William S. Bostwick, . . .	Jersey City, N. J.
George K. Bretherton, . . .	Clarkville, New Mexico.
Samuel H. Brockunier, . . .	Wheeling, W. Va.
Alfred H. Brooks, . . .	Washington, D. C.
Frederick C. Brown, . . .	Komata, Auckland, New Zealand.
W. B. Budrow, . . .	Aguas Calientes, Mexico.
Charles E. Bunker, . . .	Amador City, Cal.
John DeWitt Burgess, . . .	Tucson, Ariz.
Henry Burrell, . . .	Great Falls, Mont.
Alexander J. Campbell, . . .	Sausalito, Cal.
Charles M. Carhart, . . .	Kingston, N. Y.
Robert M. Catlin, . . .	Cape Town, South Africa.
A. T. Child, . . .	New York, N. Y.
Safford K. Colby, . . .	New York, N. Y.
John H. Collier, . . .	Tesla, Cal.
A. W. Corbus, . . .	Douglas Island, Alaska.
Charles E. Coxe, . . .	Zacualpan, Mexico.
George G. Crawford, . . .	Braddock, Pa.
Felix Cremer, . . .	Aguas Calientes, Mexico.
Isidor Davidov, . . .	Barroncuilla, Colombia, South America.
Alexander Doepel, . . .	Victoria, Australia.
William Donald, . . .	Ridgefield Park, N. J.
Charles F. Drake, . . .	Chicago, Ill.
Wilbur F. DuBois, . . .	Slocan City, B. C.
Edward B. Durham, . . .	Franklin Furnace, N. J.
James Dyson, . . .	Silverton, Colo.
William Preston Eyre, . . .	Buena Vista, Colo.
Alfred L. Foster, . . .	Auckland, New Zealand.
James Wilson Furness, . . .	Buena Vista, Colo.
James B. Gallagher, . . .	Butte, Mont.
Claude L. Goujot, . . .	Williamson, W. Va.
Frank B. Gaylord, . . .	Deseronto, Ont., Canada.

* This list includes only those candidates whose names were sent to members by mail in Circulars No. 2, April 13, 1900, and No. 3, June 12, 1900.

Leonidas C. Glenn, . . .	Columbia, S. C.
John Gordon, . . .	Rio de Janeiro, Brazil.
J. Norton Griffiths, . . .	London, England.
William T. Griswold, . . .	Washington, D. C.
William Hagemann, . . .	Sierra Mojada, Mexico.
Edward A. Haggren, . . .	Golden, B. C.
Dr. Willett L. Hardin, . . .	Lima, O.
Lawrence Bartlett Harrison, .	Eulalia, Mexico.
R. G. Hart, . . .	Berkeley, Cal.
Christopher Henne, . . .	Los Angeles, Cal.
Walter T. Holberton, . . .	Copiapo, Chile, South America.
Clarence W. Horst, . . .	Cape Town, South Africa.
Robert H. Irons, . . .	Harrisburg, Pa.
Elbridge C. Jacobs, . . .	Burlington, Vt.
Royal P. Jarvis, . . .	Leadville, Colo.
Francis Jenkins, . . .	Silver City, Idaho.
Frederick Johnson, . . .	Leadville, Colo.
Howard S. Johnson, . . .	Charleston, W. Va.
Charles C. Jones, . . .	Marquette, Mich.
Henry Kehoe, . . .	Spokane, Wash.
Edward Kelly, . . .	Port Oram, N. J.
Robert A. Kinzie, . . .	Parral, Chihuahua, Mexico.
Newton B. Knox, . . .	Bodie, Cal.
Edward L. Kraemer, . . .	Leadville, Colo.
James T. Laidlaw, . . .	Fort Steele, B. C.
William M. Lippitt, . . .	Pinos Altos, New Mexico.
Robert A. McArthur, . . .	Butte, Mont.
Edward E. McCarthy, . . .	Cambridge, Mass.
Tamaki Makita, . . .	Chikugo, Japan.
A. A. Martin, . . .	Berlin, Germany.
Emil Melzer, . . .	Bourne, Oregon.
Robert S. Mercur, . . .	Centralia, Pa.
Roscoe B. Morton, . . .	Idaho Springs, Colo.
Charles Nack, . . .	Bahia, Brazil.
Askin Nicholas, . . .	Peak Hill, North Murchison, West Australia.
H. Z. Osborne, . . .	Los Angeles, Cal.
R. A. Perez, . . .	Los Angeles, Cal.
Bert Peterson, . . .	Torres, Sonora, Mexico.
W. T. M. Pritchard, . . .	Marrikuppam, India.
Dellwyn V. Purington, . . .	Chicago, Ill.
George E. Revell, . . .	Peterboro, Ont., Canada.
John Ainsworth Rice, . . .	Bland, New Mexico.
Philip W. K. Robertson, . . .	Mexico City, Mexico.
Gilbert J. Roote, . . .	San Francisco, Cal.
Hugh Rose, . . .	Berkeley, Cal.
Murray Russell, . . .	Otago, New Zealand.
Forest Rutherford, . . .	Aguas Calientes, Mexico.
Augustin Sahlberg, . . .	El Oro, Mexico.
Harmer C. Sandifer, . . .	Guanajuato, Mexico.
Walter G. Scott, . . .	Racine, Wis.
Dennis Searles, . . .	Searles P. O., Cal.

Raymond See, . . .	Paris, France.
Prentiss Selby, . . .	Selby, Cal.
William Selkirk, . . .	Keswick, Cal.
Joseph H. Shockley, . . .	Telluride, Colo.
Henry R. Simpson, . . .	Kansas City, Mo.
Alfred M. Smith, . . .	Ballarat, Victoria, Australia.
Arthur J. Stewart, . . .	Parral, Mexico.
Lester Strauss, . . .	New York, N. Y.
William J. Sutton, . . .	Victoria, B. C.
O. R. Symmes, . . .	Grantville, Ga.
Robert Melvin Tarleton, . . .	Baltimore, Md.
C. H. Thompson, . . .	Spokane, Wash.
William Thompson, . . .	Rossland, B. C.
Abel H. Toll, . . .	Bland, New Mexico.
Lincoln A. Treat, . . .	Youngstown, O.
Samuel R. Trengrove, . . .	Mullan, Idaho.
John K. Turner, . . .	Rinconada, New Mexico.
Charles R. Van Hise, . . .	Madison, Wis.
Charles Stewart Watson, . . .	Menzies, West Australia.
Robert W. Watson, . . .	Silverton, Colo.
George Weir, . . .	Broken Hill, New South Wales.
Haarlem E. West, . . .	Libby, Mont.
F. W. C. Whyte, . . .	Belt, Mont.
Arthur Wilkinson, . . .	Johannesburg, South African Republic.
Eugene B. Willard, Jr., . . .	Hanging Rock, O.
Richard Wilson, . . .	Wallace, Idaho.
William O. Wood, . . .	Benwood, W. Va.
Allen Harvey Woodward, . . .	Woodward, Ala.
Cary Wright, . . .	Santa Fe, New Mexico.
Sidney B. Wright, . . .	Deloro, Ont., Canada.
A. F. Wuensch, . . .	Denver, Colo.
Allen M. Yonge, . . .	Havilah, Cal.

ASSOCIATES MADE MEMBERS.

H. T. Poindexter, . . .	Butte, Mont.
William C. Wallace, . . .	San Francisco, Cal.

The following list of names registered during the meeting is necessarily incomplete, by reason of the peripatetic character of the meeting, and the consequent lack of permanent headquarters :

MEMBERS, ASSOCIATES AND GUESTS REGISTERED.

Charles Archibald.	F. J. Campbell.
G. F. Baer.	J. A. Capp.
B. T. A. Bell.	C. H. Carriere.
W. T. Bonner.	James Carruthers.
J. Stevenson Brown.	E. E. Chambers.
G. L. Burritt.	J. B. Cullum.

Hiram Donkin.
J. W. Dougherty.
James Douglas.
T. M. Drown.
E. T. Dumble.
Theo. Dwight.
J. P. Edwards.
W. S. Edwards.
Charles Fergie.
Graham Fraser.
E. Gilpin, Jr.
W. L. Goodwin.
Harvey Graham.
W. L. Grammar.
T. R. Gue.
C. S. Hill.
C. S. Hinchman.
Walter Hinchman.
Levi Holbrook.
R. T. Hopper.
F. M. Huntress.
George Hes.
E. P. Jennings.
C. H. Jout.
W. L. Kann.
W. Kelly.
Wm. Koehler.
George E. Ladd.
R. G. Leckie.
James F. Lewis.
W. L. Libbey.
W. F. McCurdy.
George F. McKay.
J. S. McLennan.

A. McNeill.
M. McNeill.
W. G. Matheson.
C. A. Meissner.
W. G. Miller.
M. Morrow.
A. E. Noble.
S. M. Pitman.
Henry S. Poole.
C. H. Porter.
J. Bonsall Porter.
Theo. D. Rand.
R. W. Raymond.
R. B. Ross.
H. J. Seaman.
Horace See.
D. M. Sexton.
A. W. Sheaffer.
John M. Sherrerd.
J. W. Shook.
George R. Smith.
T. Guilford Smith.
C. C. Starr.
George W. Stuart.
W. D. Taunton.
C. H. Tompkins.
F. Valentine.
M. D. Valentine.
C. H. Wellman.
A. H. Wethey.
E. L. Wiles.
J. F. Wilcox.
Walter Wood.
W. I. Wrightson.

EXCURSIONS AND ENTERTAINMENTS.

The Council having accepted the cordial invitation of the Canadian Mining Institute and the Mining Society of Nova Scotia to hold the summer meeting in joint session with them, and visit the principal metallurgical and mining centers of Nova Scotia and Newfoundland, a special train of Pullman sleepers, with dining-car, baggage-car, etc., was engaged to make the trip through Canada and Nova Scotia, beginning and ending at Quebec, for the accommodation of members and guests of this Institute. A small party of 35 left New York for Quebec in two special cars, which were afterwards attached to the excursion-train at Levis. The Institute gratefully acknowledges the courtesies of the American and Canadian railroads; the cordial hospitality, unbounded liberality and unwearied assiduity of its hosts, the two societies above named;

and the friendly interest shown in this meeting by the government of the Dominion of Canada, and the provincial governments of Quebec and Nova Scotia.

The numerous excursions and entertainments were arranged by the General Committee, under the able direction of its chairman, Mr. James F. Lewis, of Sherbrooke, and its secretary, Mr. B. T. A. Bell, of Ottawa, effectively aided by Mr. W. L. Libbey, President, and Mr. H. M. Wylde, Secretary, of the Mining Society of Nova Scotia. An attractive souvenir programme of more than 100 pages, containing, besides the schedule of excursions, much valuable information on the mineral resources and the mining industry of Nova Scotia, with a profusion of beautiful illustrations, had been compiled by this committee, and was presented to all the members and guests.

Sherbrooke, Quebec.

On Friday, August 17th, at 4.15 P.M., the New York party already mentioned left for Quebec on the New York, New Haven and Hartford, Boston and Maine, and Quebec Central railways, and reached Sherbrooke early the next morning, when they were joined by a number of members of the Canadian Mining Institute. A committee of citizens,* headed by Mr. James F. Lewis, President of the Canadian Rand Drill Co., escorted them to the Magog House, where breakfast was served and a formal welcome was extended by representatives of the Mayor, City Council, Board of Trade and Citizens' Committee. The party then visited the mills of the Dominion Carpet Co., Victoria Park, the shops of the Jenckes Machine Co., the Sherbrooke electric light station, the Paton woolen mills, and finally the shops of the Canadian Rand Drill Co., where the manipulation, by compressed-air, of power-hammers, traveling-cranes and air-hoists in the manufacture and test of compressed-air drills was exhibited and explained. Luncheon was served in the new pattern-shop of the Company; and, after some informal speech-making, the party, augmented by many Sherbrooke friends, resumed its journey to Thetford on a special train, furnished

* *Sherbrooke Reception Committee*: Mayor L. C. Belanger, *Chairman*; J. F. Lewis, John Blue, F. P. Buck, William Farwell, John M. Jenckes, H. D. Lawrence, F. C. Thompson, James S. Mitchell, Rufus Pope, M. P., Col. C. King, S. W. Jenckes, Frank Grundy, J. O. Camirand, Gen. P. Lang; James R. Woodward, *Secretary*.

by the courtesy of Messrs. Frank Grundy, general manager, and J. H. Walsh, general passenger agent, of the Quebec Central railway.

Thetford, Quebec.

At 5 P.M. the party reached Thetford, and was escorted at once to the asbestos mines by managers of the Bell's Asbestos Co., Ltd., Johnston's Co., and King Bros. Asbestos Co., and other members of the reception committee.*

About 85 per cent. of the total asbestos-production of the world must be credited to the Quebec mines, the earliest of which were developed in the deposits of Thetford twenty years ago. After a hasty inspection of the great mining-pits and separating-works, the party was entertained at dinner in the Thetford Club, and continued its journey, reaching Quebec at 11 P.M. to join the western members of the Institute and the Canadian contingent, which had arrived earlier in the day, and to receive an informal welcome at the Chateau Frontenac from Hon. A. Tourgeon, M.L.A., Commissioner of Colonization and Mines for the province, representing the provincial and city authorities.†

Quebec.

On Sunday morning the visitors took advantage of the fine weather and the hospitality of their entertainers to visit the points of interest in this picturesque historic city. Some made a tour of the city and citadel in special electric cars, while others, at their own pleasure, visited the fortifications, the Heights of Abraham, the convents and churches, the winding streets and quaint houses of the lower town, or enjoyed the superb prospect of the St. Lawrence from the new Dufferin terrace. On the government steamer "Druid," kindly placed at its disposal by the Canadian Minister of Marine and Fisheries, the party was conveyed in the afternoon, under the friendly guidance of Commodore J. U. Gregory, and to the accompaniment of festive music by the Royal Artillery Band, to Sillery and the site of the proposed new bridge, "Beauvoir," the beautiful residence of the Hon. R. R. Dobell, and down the

* *Thetford Reception Committee* · George R. Smith, *Chairman*; Andrew Johnson, B. Bennett, Dr. James Reed, T. H. Crabtree, Hugh Leonard, R. T. Hopper.

† *Quebec Reception Committee* · Hon. A. Tourgeon, *Chairman*; C. H. Carriere, Frank Carrell.

St. Lawrence to Montmorenci Falls, Louise Basin and various points of scenic and historical interest, as far as the Island of Orleans. In the evening the special train left Levis for Sydney, Cape Breton.

During the following day (Monday) the route lay through the beautiful Metapedia Valley, the famous salmon- and trout-fishing region, and along the Baie de Chaleur and the Gaspé peninsula. Sydney was reached in the forenoon of Tuesday, August 21st.

Sydney, Cape Breton

The visitors were met upon their arrival by Mayor Crowe, the members of the local committee,* and officers of the Dominion Iron and Steel Co., and were conducted to the new steel-plant of the said company now under construction. This company, of which Henry M. Whitney, of Boston, is president, contemplates not only the production of steel at Sydney, but also the mining of iron-ore at Belle Isle; Newfoundland, the quarrying of limestone at George's River, Cape Breton, and the manufacture of coke from the coal-mines of the Dominion Coal Co. The new coke-plant will be similar to that of the New England Gas and Coke Co., built by Mr. Whitney at Everett, Mass., which uses the Cape Breton coal as raw material. It will comprise eight batteries, of 50 Otto-Hoffman by-product coke-ovens each, with a total capacity of 1600 tons of coke daily. The gas will be used in the company's open-hearth furnaces, while the ammonia and coal-tar will be marketed. The steel-plant is situated directly on Sydney harbor, and covers 450 acres of land. It is to include four 350-ton blast-furnaces, open-hearth furnaces with a daily capacity of 1400 tons of steel, blooming-mill, machine-shop and foundry, wharfs and all necessary dependencies. Excepting the machine-shop and blast-furnace plant, heavy concrete foundations are as yet the only visible signs of the main buildings.

After an interesting morning, the visitors were entertained at luncheon in a large dining-hall recently erected for the company's employees, where speeches were made by Mr. A. J. Moxham, manager of the company, by the President and Sec-

* *Sydney Reception Committee* Mayor Crowe, *Chairman*, Hiram Donkin, A. J. Moxham, J. G. S. Hudson, F. C. Kimber, R. H. Brown, C. A. Meissner, A. C. Ross, J. T. Burchell.

retary of the Institute, and others. The party then resumed its inspection of the new furnace-plant and docks, visited the great International shipping piers of the Dominion Coal Co., and returned to Sydney.

In the evening, a joint meeting was held at Rosslyn Rink under the auspices of the Canadian Mining Institute.

The morning of Wednesday, August 22d, was spent in visiting, by special train, the extensive collieries of the Dominion Coal Co. This company is the owner of 160 square miles of coal leases, in which it is estimated that 3,000,000,000 tons of workable bituminous coal are available. The collieries comprise the Reserve, International, Caledonia and Dominion No. 1, with an aggregate monthly output of 208,000 gross tons, and the Dominion No. 2, No 3 and No 4, which are now in course of sinking. The coal-washing plant consists of two Robinson-Ramsay coal-washers, and has a capacity of 2000 tons of washed coal per day. After luncheon and complimentary after-dinner speeches, in the handsomely decorated dining-room of Dominion No. 4 colliery, the party made a short inspection of the company's shipping-piers at Louisburg, which form, with those at Sydney, already mentioned, the two termini of the railway. A delightful hour was afterwards spent among the ruins of the old fort, under the guidance of Mr John S. McClelland, who explained the main points of interest and recalled many historical reminiscences of the stormy scenes there enacted during the seventeenth century. On the return to Sydney a brief stop was made at the coal-washing plant at Morien.

The Bras d'Or Lakes

On Thursday, August 23d, the visitors enjoyed, by courtesy of the Mayor and Corporation of the town of Sydney and the officers of the Dominion Iron and Steel Co., a delightful excursion on the steamer "Pawnee" through the beautiful Bras d'Or Lakes, as far as Grand Narrows. The day was clear and bracing, the magnificent scenery recalled Lake George, the Hudson Highlands and the rocky shores of Lake Superior, and assuredly no more brilliant climax could have been devised to conclude the Sydney visit than this voyage upon an inland sea, aptly called, by the old Breton fishermen, "the Arm of Gold."

At Grand Narrows the party resumed the special train, and reached New Glasgow during the night.

New Glasgow

Friday morning, August 24th, the visitors were welcomed by the local committee,* headed by Mr. Graham Fraser, Vice-President of the Nova Scotia Steel Co., and Mr. Charles Fergie, manager of the Intercolonial Coal Co., Ltd. These gentlemen had arranged so full and attractive a programme, that it was impossible for all the guests to take all the excursions. They were therefore separated into parties, one of which inspected the Intercolonial Coal Co.'s Drummond Colliery at Westville, and was entertained at luncheon by Mr. Fergie in his beautiful home, while another visited the Acadia Coal Co.'s mine at Stellarton; and a third, including the ladies, enjoyed, through the courtesy of the Citizens' Committee, a beautiful carriage-drive around the city of New Glasgow, and to the top of Fraser's mountain.

At noon, the several parties were reunited and visited the works of the Nova Scotia Steel Co., Ltd. These works comprise an automatic coal-washing plant (the first ever erected in Canada) of 300 tons daily capacity, a coking-plant of 54 Bernard retort-ovens with a total output of 120 tons per 24 hours, and a blast-furnace (smelting largely the ores from Belle Isle, Newfoundland), all at Ferrona; while at New Glasgow is located the steel-plant, comprising four Siemens furnaces, from 20 to 50 tons capacity each, reheating-furnaces and a complete rolling-mill and machine-shop equipment, with a daily output of 150 tons of steel ingots, worked up into forgings, plates, bars and merchant-steel.

A delightful excursion on Pictou harbor, in the steamer "Princess," chartered for this occasion by the Nova Scotia Steel Co., in company with a large number of invited guests from New Glasgow, occupied the afternoon. The beautiful Scotch ballads and Canadian songs and choruses sung upon the homeward trip were the special features of the occasion.

Halifax

By courtesy of the officers and members of the Mining Society of Nova Scotia the visitors were driven on Saturday

* *New Glasgow Reception Committee* Graham Fraser, *Chairman*, Henry S. Poole, Harvey Graham, A. C. Bell, M.P., Charles Fergie, J. G. Rutherford, T. Cantley, Hon. M. MacDonald

morning, August 25th, to various points of interest, including the beautiful public gardens for which the city is noted * In the afternoon they enjoyed an excursion on the steamer "Coban," arranged by the courtesy of Mr Matthew R Morrow, and in the evening attended a clever amateur theatrical performance at the Academy of Music.

Sunday was spent in visits to the Citadel and the garrison church in the morning, and an interesting inspection in the afternoon of the British warship Crescent, where Lieut Gillett courteously entertained the party.

A session of the Institute occupied the morning of Monday, August 27th, and in the afternoon the steamer "Chebucto" carried the party about the harbor to view the famous York Redoubt and other forts, as well as the beautiful residences of wealthy business and professional men. A large number of eminent citizens and their ladies accompanied the party, and after luncheon, addresses of welcome and cordial appreciation were exchanged.

On Tuesday, August 28th, under the escort of D. C. Hood, the secretary, and J. C. McNulty, manager, and accompanied by the Hon. W. S. Fielding, M. P., Dominion Minister of Finance, the party visited the Tunnel mine of the Waverly Gold Mining Co. A modern 60-stamp mill has recently been erected here. Luncheon was served in a large tent erected on the lake shore near the mine, and after numerous hearty and eloquent speeches, the party returned to Halifax, and attended in the evening a concert in the Public Gardens, where Sir Charles Tupper delivered a patriotic address to the soldiers lately returned from the South African war.

On Wednesday morning, August 29th, a majority of the members departed for their homes by way of Quebec, while a party of about 25, under the guidance of Mr. B. T. A. Bell and of Mr. J. M. Sherrerd, who kindly volunteered to superintend all arrangements for the comfort of the Institute party *en route*, inspected the old Sydney collieries of the Nova Scotia Steel Co., where they enjoyed the hospitalities of Mr. R. H. Brown and his daughters, and then left for Newfoundland.

* *Halifax Reception Committee* W. L. Libbey, *Chairman*, George W. Stuart, B. F. Pearson, M. R. Morrow, D. C. Hood, Alexander McNeil, C. C. Starr, George E. Francklyn, Geoffrey Morrow, A. A. Hayward, B. C. Wilson, T. R. Gue, G. L. Burritt, Dr. Gilpin, H. M. Wylde, *Secretary*

Newfoundland

The trim steamer "Bruce," placed at the disposal of the party by the generous courtesy of Mr. R. G. Reid,* proprietor of the Newfoundland railway, landed the excursionists early on Friday morning, August 31st, in the rugged and picturesque harbor of Port aux Basques, where a special train was in waiting to carry them to St. Johns. Much enthusiastic interest in the rich variety and natural beauty of Newfoundland scenery was expressed by the visitors during this daylight journey. On Sunday morning a special train left St. Johns for Killigrew's, and in spite of the drawbacks of cold and windy weather and an ugly sea, a memorable visit was paid to the Belle Isle iron-mines. Those who ventured the trip were amply repaid by the warm hospitality of Mr. R. E. Chambers and assistants, of the Nova Scotia Steel Co.'s mines, Mr. W. S. Grammer and assistants, of the Dominion Iron and Steel Co.'s mines, and their ladies.

During the brief visit to St. Johns, Mr. H. C. Burchell, government engineer, and his wife, were assiduous in their attentions to the party, and Hon. Edgar Bowring entertained them at his South Side works, where they witnessed the dressing and treatment of the pelts of the hair-seals brought in by steamers.

On Tuesday, September 4th, the visitors sailed on the steamer "Bonavista," kindly placed at their disposal by Mr. H. M. Whitney, and, after a voyage made doubly delightful by the courtesies of Captain Frazer, arrived at Sydney, whence they proceeded to their several homes.

* Mr. Reid extended similar courtesies to a small party which visited Newfoundland, leaving the main party at Sydney, during the previous week.

P A P E R S.

The Work of the United States Geological Survey in Relation to the Mineral Resources of the United States.

BY CHARLES D WALCOTT, DIRECTOR, WASHINGTON, D C

(Washington Meeting, February, 1900)

INTRODUCTION.

THE organic law of the Geological Survey provides that its Director "shall have the direction of the geological survey, and the classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain."

Under these broad general provisions, the first Director, Clarence King, laid out a comprehensive plan of operations in the States west of the 102d meridian Of this he said *

There can hardly be two opinions on the desirableness of immediately working out such problems in these great districts which, in their past and present history, offer examples of instructive geological structure and great bullion-yield, and which have required of mining men special mechanical skill and large outlay of capital Proper scientific reports on such typical districts become records of remarkable phenomena in the field of industrial geology and chronicles of distinguished success in the department of mining engineering Among the great numbers of mining-districts which merit rigid investigation I have chosen three, which more than others seemed to offer harvests of technical information, of which the mining population stands in immediate need. Leadville, the extraordinary district in Middle Colorado, Eureka, Nevada, which for fifteen years has been the most productive silver-lead district in America, and the incomparable Comstock Lode, are chosen as the first three districts to be illustrated by special monographs

All of these investigations were completed, and the reports were published, after Mr. King resigned the Directorship of the Survey in 1881.†

His successor, Director Powell, was confronted with the prob-

* *First Annual Report, U S Geol Survey*, 1880, p 8

† An admirable review of the mining work of the U S Geological Survey under its first Director is contained in *Trans*, x, 412

lem of the extension of the survey over the entire United States and the examination of the mineral resources of the country. Plans were formulated for the investigation of the copper- and iron-deposits of the Lake Superior region, the iron- and coal-deposits of the Appalachian area south of the Potomac, the phosphate-deposits of Florida, and many minor areas of economic interest. Maps suitable as a basis for geologic and mining work were not in existence. Year after year the topographic survey was pushed ahead, the geologic work being limited to the regions of which maps were available. For the mining engineer it was a long, tedious period of waiting; and many became restless. Another complication arose. The West wished to know more of its irrigation-possibilities; and energy and money were diverted to irrigation-surveys. This function culminated in 1890, when Congress cut off the irrigation-work for a time. Mining and economic work began to push to the fore again, until August, 1892, when the appropriation for geology was cut down by legislative action from \$115,000 to \$50,000, for chemistry, from \$17,000 to \$5,000, for scientific salaries, from \$67,700 to \$29,900, for engraving geological maps, from \$60,000 to \$10,000; for illustration of reports, from \$16,000 to \$5,000, and for paleontology, from \$40,000 to \$10,000. Topography nearly escaped, the change being from \$250,000 to \$240,000. Readjustments were made from year to year, and some of the amounts have been restored, so that at the present time the general work of the Survey is progressing in a satisfactory manner, with the exception of mining geology and the statistics of mining and mineral production.

It is well understood that good topographic maps must precede areal geology, and that the latter must be worked out and platted before deductions of permanent value can be made in relation to the extent or permanency of a mining-region or district. With this in view, the present policy of the Geological Survey in relation to mining will be best shown by a brief review of the work under way during the last field-season.

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SURVEYS.

Topographic Surveys.—The area (square miles) covered by topographic surveys during 1899 is as follows

Division	Scale, 1 Mile to Inch	Scale, 2 Miles to Inch	Scale, Special	Total
Atlantic Division	6,591	3,345		9,936
Central Division	3,648	7,125	32	10,805
Rocky Mountain Division	90	7,784	55	7,929
Pacific Division	388	6,782	24	7,194
Total	10,717	25,036	111	35,864

As in some previous years, there was a certain amount of re-surveying, for the purpose of adjusting to the requirements of present standards of precision maps which had been made under less exacting conditions, and the area thus covered was 6364 square miles.

All the topographic work has an economic value, but not always to mining industries. Yet much of it is important to mining, especially in the States where the mineral product is large.

The present condition of the topographic surveys is shown in the table on page 6. The history of these surveys is given in Part I of the Twentieth Annual Report, pp 90-102.

Geologic Surveys—In New York and Vermont the detailed study recently made of the great roofing-slate belt was supplemented in 1899 by the survey of adjoining areas into which the slate-bearing series extends. The work on the iron-bearing formations of the Adirondack Mountains, New York, was continued, and in Maryland co-operation with the State Survey resulted in the survey of the marl-bearing series. The mapping of the coal-fields of West Virginia was advanced by 1,000 square miles of area, and in Illinois the survey of the Danville quadrangle was completed. In the glaciated regions of Wisconsin, Illinois, Indiana, Michigan and Ohio, investigations were continued in the glacial gravels and clays, which have great economic importance to the people of the areas where they occur.

The Survey has recently published an extended monograph on the Crystal Falls iron-bearing district of Michigan. In the last season the Lake Vermilion district was under survey, and this work, with the topographic surveys in the Mesabi region, was well advanced. The mapping of the coal-fields of Indian Territory in the vicinity of McAlester, and thence southward, was pushed forward.

Present Condition of Topographic Surveys and the New Areas Surveyed from July 1, 1899, to February 20, 1900

(Areas revised or resurveyed are not included in this table)

State or Territory	Total Area	Area Surveyed in 1899-1900	Area Surveyed to Date, February 20, 1900	
			Square Miles	Per cent
Alabama	52,250	482	15,545	30
Arizona ..	113,020	400	57,190	50
Arkansas	53,850	1,930	16,434	31
California	158,360	3,394	53,002	33
Colorado	103,925	874	34,005	32
Connecticut	4,990		4,990	100
Delaware	2,050		644	31
District of Columbia	70		70	100
Florida	58,680		1,821	3
Georgia	59,475	515	14,522	24
Idaho	84,800	1,153	13,744	17
Illinois	56,650		4,485	8
Indiana	36,350	478	621	2
Indian Territory	31,400	10	30,895	99
Iowa	56,025	1,191	7,886	14
Kansas	82,080		62,746	76
Kentucky	40,400		10,433	26
Louisiana	48,720		7,492	15
Maine	33,040	426	4,236	13
Maryland	12,210	951	9,401	77
Massachusetts	8,315		8,315	100
Michigan	58,915		1,964	3
Minnesota	83,365	656	2,278	3
Mississippi	46,810		20	
Missouri	69,415	932	29,801	43
Montana	146,080	35	36,188	25
Nebraska	77,510	1,704	26,804	35
Nevada	110,700		28,949	26
New Hampshire	9,305		2,396	26
New Jersey	7,815		7,815	100
New Mexico	122,580		27,777	23
New York	49,170	3,345	21,737	44
North Carolina	52,250		12,252	23
North Dakota	70,795		6,327	9
Ohio	41,060	966	1,828	4
Oklahoma ..	39,030		4,146	11
Oregon	96,030	433	14,138	15
Pennsylvania	45,215	1,257	7,895	17
Rhode Island	1,250		1,250	100
South Carolina	30,570		3,900	13
South Dakota	77,650	250	16,523	21
Tennessee	42,050	750	18,391	44
Texas	265,780		58,427	22
Utah	84,970		62,867	74
Vermont	9,565		2,844	30
Virginia	42,450		29,227	69
Washington	69,180	2,013	8,471	12
West Virginia	24,780	150	17,176	69
Wisconsin	56,040	2,035	8,312	15
Wyoming	97,890	3,170	16,199	17
Totals	3,024,880	29,500	834,388	28

In the Rocky Mountain region the survey of the gold-bearing rocks in the San Juan Mountains of southwestern Colorado was pursued during the entire season, the topographic maps being prepared on the scale of one mile to the inch.

The detailed economic survey of the Deadwood district in the Black Hills was practically completed, the areal geology having been mapped during the last two years. In Montana work was continued in the Elkhorn district, and a careful re-survey was made of the mines in the Butte district, for the revision of the geologic map of Butte and vicinity. The exploration of the almost unknown area of Central Idaho was continued during the field-season, and valuable data were secured for future detailed work. An extended reconnaissance was also made through the Basin ranges of Utah and Nevada, with a view to future work. In the Silver Peak gold-district of Nevada the areal geology was completed.

For several years studies have been made of the physical conditions of gold-deposition in California, especially with reference to the Mother Lode. It is anticipated that this work will be brought to a close during the season of 1900, and that a monograph will be published on the subject. The areal geology of the gold-belt has all been mapped, and much of it published. Investigations were also made in California with relation to the deposits of oil and asphalt. In Oregon a reconnaissance was carried through the Klamath Mountains with the view of determining their mineral resources, and the desirability of making detailed maps. Some work was carried on in Washington two years ago, and the present season the areal geology of the Mount Stuart quadrangle and of a considerable portion of the Snoqualmie quadrangle to the west was completed.

In Alaska a reconnaissance was made of the Upper Koyukuk region, also of the area about the headwaters of the Tanana, and late in the season, of the Cape Nome district.

In addition to the above-mentioned special investigations, visits were made by geologists to many areas in various sections of the country, with a view to the prosecution of work in the future. The work of the division of Mineral Resources was pushed forward energetically under a substantial increase of its appropriation. The field examination of the distribution, extent

and value of special minerals was enlarged, by taking up asphalt-deposits, while the problems of phosphates, fuller's-earth, etc., received additional attention

Progress-Map, 1879-1900.—It has been customary to present in the annual reports a progress-map showing the condition of the work of the topographic branch of the Survey; but the accompanying map presents for the first time the combined results of both topographic and geologic surveys. It shows separately the topographic surveys on the scales of 1, 2, and 4 miles to the inch, and the areas of geologic reconnaissance and detailed geologic surveys.

The following summary, broadly arranged under special minerals, gives a general view of the geologic work represented geographically on the progress-map

PROVISIONAL LIST OF SURVEYS, TO ACCOMPANY THE PROGRESS-
MAP, 1879-1900, WITH PARTIAL REFERENCE TO RELATED
PUBLICATIONS

General Surveys

Topographic surveys, scales 1, 2, and 4 miles to the inch.

Geologic reconnaissances.

Detailed geologic surveys, including investigation of mineral and artesian-water resources in general, published, or in preparation for publication, as folios of the Geologic Atlas, as papers in the Annual Reports, or as Bulletins and Monographs.

Geologic folios published, 56

Geologic folios initiated, and in various stages of preparation, 61

Coal, Oil, and Gas

Appalachian—Bituminous field—Campbell, Keith, Hayes, Wilhs, Darton, Taff, Weeks—14th and 17th Annual Reports; Bulletin No 111, Geologic Atlas of the United States, folios Nos. 6, 8, 12, 19, 21, 22, 26, 28, 33, 34, 35, 40, 44, 46, 47, and 53, and others in preparation.

Pennsylvania—Anthracite-field—David White—20th Annual Report.

Massachusetts—Narragansett coal-field—Shaler, Woodworth, Foerste—Monograph XXXIII.

- Virginia—Richmond basin—Shaler, Woodworth—19th Annual Report
- Illinois—Danville quadrangle—Campbell—Geologic folio in preparation
- Ohio and Indiana—Gas- and oil-field—Orton—8th Annual Report.
- Indiana—Gas-region—Phinney—11th Annual Report.
- Indian Territory—Coal-field—Taff—19th and 21st Annual Reports and five geologic folios in preparation
- Texas—Rio Grande coal-fields—Vaughan—Bulletin No 164
- Texas—Corsicana oil-field—Hill—Report in preparation.
- Colorado—Denver basin—Emmons, Cross, Eldridge—Monograph XXVII
- Colorado—Anthracite and Crested Butte quadrangles—Emmons, Cross, Eldridge—Geologic folio No. 9.
- Colorado—Durango and La Plata quadrangles—Cross—Geologic folios in preparation
- Colorado—Elmoro, Spanish Peaks, and Walsenburg quadrangles—R C Hills—Geologic folio No 58 and two in preparation.
- Colorado—Florence oil- and gas-field—Eldridge—*Trans. A. I. M. E.*, vol. xx.
- Wyoming—Coal- and oil-fields—Eldridge, reconnaissance—Bulletin No. 119
- Montana—Livingston and Fort Benton quadrangles—Weed—Geologic folios Nos. 1 and 55.
- Montana—Great Falls and Red Lodge areas—Weed—G. S. A. Bull., vol 3.
- Montana—Judith Mountains—Weed—18th Annual Report.
- Montana—Cinnabar and Bozeman field—Weed—Bull. Geol. Soc. Am., vol. 2.
- Washington—Tacoma coal-field—Willis, Smith—18th Annual Report and Geologic folio No. 54
- Washington—Mount Stuart quadrangle—Smith—Geologic folio in preparation.
- Oregon—Coos Bay basin—Diller—19th Annual Report.
- California—Mount Diablo—Turner—Bull. Geol. Soc. Am., vol. 2.
- California—Jackson quadrangle—Turner—Geologic folio No. 11
- Alaska—General report—Dall—17th Annual Report.

Iron-Ore.

- Appalachian—Clinton ores—Hayes, Keith, Darton—Geologic folios Nos. 2, 4, 6, 8, 12, 14, 19, 20, 21, 26, 28, 32, 33, and 35.
- Appalachian—Southern limonites—Hayes—*Science*, 1897
- North Carolina—Magnetites—Keith—Report and Geologic folio in preparation.
- New York—Adirondack magnetites—Kemp—19th Annual Report, geologic folio in preparation, and *Trans. A. I. M. E.*, vol. xxvii.
- Michigan—Lake Superior iron-districts—Irving, Van Hise, Bayley, Clements, Smyth—10th, 15th, and 19th Annual Reports, Monographs Nos. XIX, XXVIII, and XXXVI, and special geologic folio in preparation
- Minnesota—Vermilion and Mesabi iron-districts—Van Hise—Reports in preparation.
- Montana—Little Belt Mountains—Weed—20th Annual Report and Geologic folio No. 56.

Gold, Silver, and Associated Metals.

- Appalachian—Southern gold-fields—Becker, Keith, Hayes—16th Annual Report and geologic folios in preparation.
- South Dakota—Black Hills—Emmons, Jaggar—21st Annual Report (in preparation) and geologic folio in preparation
- Colorado—Leadville—Emmons—Monograph XII, and 2nd Annual Report.
- Colorado—Tenmile district—Emmons—Special Geologic folio No. 48.
- Colorado—Aspen—Emmons, Spurr—Monograph XXXI.
- Colorado—Anthracite and Crested Butte quadrangles—Emmons, Cross, Eldridge—Geologic folio No. 9.
- Colorado—Rosita Hills and Silver Cliff—Cross, Emmons—17th Annual Report.
- Colorado—Cripple Creek—Cross—16th Annual Report and Geologic folio No. 7.
- Colorado—Telluride, La Plata, Rico, and Silverton quadrangles—Cross, Purington—18th Annual Report, 21st Annual Report (in preparation); Geologic folio No. 57, and others in preparation.
- Utah—Mercur district—Emmons, Spurr—16th Annual Report.

- Utah—Tintic—Emmons, Tower, Smith—19th Annual Report.
Geologic folio in preparation.
- Wyoming—Absaroka—Hague—Geologic folio No 52
- Montana—Fort Belknap Indian Reservation and Bearpaw Mountains—Weed—*Am. Jour. Sci*, 1896, *Jour. Geol*, 1896.
- Montana—Judith Mountains—Weed—18th Annual Report;
Eng. and Mining Jour, 1896
- Montana—Boulder quadrangle—Weed—In preparation
- Montana—Elkhorn mining region—Weed—21st Annual Report (in preparation)
- Montana—Butte—Emmons, Weed—Special Geologic folio No. 38
- Montana—Neihart, Barker, and Yogo districts—Weed—20th Annual Report.
- Montana—Castle Mountain district—Weed—Bulletin No 139
- Montana—Little Belt and Fort Benton quadrangles—Weed—
Geologic folios Nos. 55 and 56
- Idaho—Idaho Basin and Boise Ridge—Lindgren—18th Annual Report.
- Idaho—Silver City, De Lamar, Wood River, Florence, Warren, and Seven Devils—Lindgren—20th Annual Report.
- Idaho—Elk City, Buffalo Hunt, Pierce City, and Cœur d'Alène—Lindgren—In preparation.
- Washington—Mount Stuart quadrangle—Smith—Geologic folio in preparation.
- Oregon—Coast gravels—Diller—14th Annual Report.
- Oregon—Northwest Oregon—Diller—17th Annual Report.
- Oregon—Bohemia mining-region and the Blue River mining-region—Diller—20th Annual Report.
- Nevada—Eureka district—Hague, Curtis—Monographs VII and XX, and 3rd and 4th Annual Reports.
- Nevada—Comstock lode and Washoe district—Becker—Monograph III and 2nd Annual Report.
- Nevada—Silver Peak quadrangle—Turner—Geologic folio in preparation.
- California—Gold Belt—Lindgren, Turner, Diller, Ransome—
Geologic folios Nos. 3, 5, 11, 15, 18, 29, 37, 39, 41, 43, 51, and others in preparation, 8th, 14th, and 17th Annual Reports.
- California—Calico district, Barclay—Lindgren—*Trans. A. I. M. E.*, vol. xv.

Alaska—Southern gold-fields—Becker—18th Annual Report.
 Alaska—Yukon and other gold-fields—Spurr, Eldridge, Schrader, Brooks, Mendenhall—Special Alaska reports, 1898 and 1899, 18th and 20th Annual Reports.

Quicksilver.

Texas—Terlingo district—Hill—Report in preparation.
 California and Nevada—Coast Ranges of California, and Steamboat Springs, Nevada—Becker—Monograph XIII and 8th Annual Report.

Bauxite.

Alabama—Appalachian province—Hayes—*Mineral Resources of the U. S. for 1893*, and 16th Annual Report.

Copper, Zinc, and Lead

Wisconsin—Lake Superior copper-belt—Reconnaissance and compilation, Irving—Monograph V and 3rd Annual Report.
 Montana—Butte district—Emmons, Weed—Special Geologic folio No 38.
 Tennessee—Ducktown district—Hayes, Keith—Geologic folio in preparation.
 North Carolina and Virginia—Virgihna, Gold Hill, and Linden copper districts—Weed—21st Annual Report (in preparation).
 New Jersey—Franklin Furnace zinc-deposits—Wolff—Geologic folio in preparation.
 Missouri—Mississippi Valley zinc- and lead-deposits—Jenney—*Trans A. I. M. E.*, vol. xxii.

Slate and Marble.

Tennessee—"Tennessee" marble—Keith, Hayes, Campbell—Geologic folios Nos. 4, 10, 12, 16, 25, and 27.
 Georgia—"Georgia" marble—Hayes, Keith—Geologic folios in preparation
 Massachusetts—Stockbridge marble—Dale, Hobbs, Emerson—Geologic folios in preparation.
 Tennessee—Ocoee slates—Keith, Hayes—Geologic folios Nos. 16, 25, and others in preparation.
 New York and Vermont—Slate-belt—Dale—19th Annual Report and geologic folios in preparation.

Phosphates and Marls

Tennessee—Phosphate districts—Hayes—17th Annual Report
 Florida—Phosphate district—Eldridge—*Trans. A. I. M. E.*,
 vol. xx, and detailed report in preparation
 Maryland and Virginia—Marls—Darton—Geologic folio No.
 23, and others in preparation.

Asphalts

Utah—Uinta Basin—Eldridge—17th Annual Report
 Indian Territory—McAlester, Antlers, and Windingstair quad-
 rangles—Taff—*Am. Jour. Science*, 1899, and geologic folios
 in preparation.
 Texas—Uvalde quadrangle—Vaughan—18th Annual Report.
 Texas—Burnet deposit—Hill—Report in preparation.
 California—San Luis Obispo district—Fairbanks—Geologic
 folio in preparation
 United States—General investigation of the deposits in West
 Virginia, Kentucky, Missouri, Colorado, Indian Territory,
 Texas, and California.—Eldridge—Report in preparation

Artesian Water and Reservoir-Sites

Atlantic Coastal Plain—Darton—Bulletin No. 138.
 Illinois—Water-resources—Leverett—17th Annual Report.
 Indiana and Ohio—Well-waters—Leverett—18th Annual Re-
 port and Water-Supply Papers Nos. 21 and 26
 Kansas—Underground waters, Southwest Kansas—Haworth—
 Water-Supply Paper No. 6.
 Kansas, Colorado, and Nebraska—Water-resources, Great
 Plains—Robert Hay—16th Annual Report.
 Dakotas—Artesian waters, Eastern Dakota—Darton, Todd—
 17th and 18th Annual Reports and Water-Supply Paper 33
 Dakota and Wyoming—Black Hills—Darton—21st Annual
 Report (in preparation).
 Nebraska—Water-resources, Western Nebraska—Darton—
 19th Annual Report.
 Nebraska—Water-resources, Southeast Nebraska—Darton—
 Water-Supply Paper No. 12.
 Colorado—Pueblo, Apishapa, and Nepesta quadrangles—Gil-
 bert—Geologic folio No. 36 and two in preparation.
 Colorado—Arkansas Valley—Gilbert—17th Annual Report.

Colorado—Spanish Peaks, Walsenburg, Elmore, and Huerfano Park quadrangles—R. C. Hills—Geologic folios in preparation.

Texas—Artesian waters—Hill, Vaughan—18th and 21st Annual Reports.

Utah—Salt Lake City—Newell—12th Annual Report.

Arizona—Gila River, storage-water—Lippincott—Water-Supply Paper No. 33.

California—Southern California—Lippincott—Water-Supply Paper in preparation.

Washington—Artesian basins, Southeast Washington—Russell—Water-Supply Paper No. 4.

ECONOMIC WORK AND THE MINING INDUSTRY

In government organizations depending upon the will of so complex a body as Congress, it is often difficult to carry out a policy outlined in advance. Usually the policy is modified by considerations, not of what it is abstractly best to do, but of what it is possible to do. This compels the administrative officer to aim at the nearest attainable approximation to the desired object.

Emmons has well said that there are three standpoints from which the relations of the Geological Survey to the mining industry in general may be viewed. first, the more purely scientific or geologic side, second, the technical side, and third, the commercial side.

The general principle upon which the Survey has been doing its economic mining work is, that it should endeavor to accomplish for the mining industry, as a whole, what the individual mining engineer or mine-owner cannot succeed by his unaided exertions in doing; that it should not undertake to do what could be done as well, if not better, by individual exertion; that it should not interfere, either favorably or unfavorably, with the private business of individuals or corporations, or enter into competition in their legitimate occupations with professional men, such as mining engineers, etc. This is implied in the clause of the organic law of the Survey which provides that—"The Director and members of the Geological Survey . . . shall execute no surveys or examinations for private parties or corporations"

If it were more generally understood that such is a proper limitation of the work of the members of the Survey, they would not be asked, as they frequently are, to tell some individual or corporation whether his or its land contains valuable mineral-deposits, since all the information they are at liberty to impart with regard to that land is contained in the published maps and reports, which may be obtained by all. If the individual or corporation is unable to deduce from these publications all the commercial data that may be desired, a mining engineer should be employed for the purpose. An attempt by the Survey to acquire and communicate such information respecting any special parcel of land would be in the nature of a report for private parties, which would be an interference with the business of the mining engineer and a violation of law. Neither should the Survey be called upon to assay or analyze ores for private parties, for that is manifestly interference with the business of the assayer; nor should it be called upon, as it sometimes is, to tell a man what process, or which of two or more processes, is best adapted for the treatment of his ores. Even if the members of the Survey were fitted to pass judgment upon the relative value of technical processes or machines, and should pronounce such judgments, they would naturally be regarded as interfering unwarrantably with the business of the person or corporation owning a process or machine which was not favorably considered in their report. If it were proper that work of this nature should be done, it would be impossible to acquire the knowledge necessary to meet such demands with the amount of money at present available, or even with ten times that amount.

The means for economic work being limited, only a small proportion of the broad field opened for investigation can be occupied at any one time. On this account, the energies of the survey have been devoted to those branches of investigation which were of immediate use to the greatest number; and these have been, in the main, investigations leading to broad general deductions.

Geologic Investigation.—In the field of more purely geologic investigation, the general object has been the determination of laws which govern the formation of deposits of the useful minerals, and of the rock-formations in which they are most likely

to be found. This object can be attained only by long and careful study of many and varied deposits—as far as possible in the condition in which they were originally formed. Ore-deposits are as a rule the result, not of a single process, but of many successive concentrations of minerals; and in those deposits which are found near the present surface, the effects of the latest of these processes—weathering or the action of surface-waters—are likely to have obscured all others. In order best to accomplish the object sought, the first studies were made of mining-districts in which mining developments have been most extensive, the mines are deepest, and the most varied forms of ore-deposits have been disclosed.

In the prosecution of these studies, the geologists often obtain results of immediate value to the miners and mine-owners of the particular district under investigation, such as the determination of the probable direction which the ore-bodies will take in unexplored ground, the faults which are likely to cut them off, and other obvious limitations which geologic conditions may suggest. These results are often of secondary importance as compared with the more general deductions, being useful to only a few persons interested in a limited district, while the general deductions, if correct, are of benefit to the whole mining community.

A brief statement of the underlying principles which govern our choice of fields of work is made, because that work has been frequently criticised. the criticism made by miners being that the Survey chooses developed districts, where the general facts with regard to ore-deposits are already known, rather than undeveloped districts, where the predictions might be of more use to those who own mines, and might actually help in their development. From a partially developed district we can usually learn only superficial facts, which are not likely to yield any contribution to general laws. Whatever may be said of the probable value of such a district belongs to the province of the mining engineer rather than to that of the Government geologist, since it involves such preliminary work as sampling of ores, prospecting, development, etc., which the geologist cannot do.

Another criticism has been that more work is done in one State than in another. But if it be admitted that the principles mentioned should govern our work, it is evident that we can-

not be guided by geographic or political considerations, but that we must study ore-deposits where they can be studied to the best advantage. In the topographic work of the Survey a more or less general geographic distribution has been possible, and it is also desirable, but in geology the Survey must continue to be the judge of the importance and interdependence of the problems to be solved, and of the best method of solving them.

In the original plan of Survey-publication, the monographs were designed to set forth each the results of a complete and, so far as possible, exhaustive treatment of a given subject or group of geologic phenomena; the bulletins were intended for reports of special studies, not necessarily exhaustive, but, for one reason or another, deserving of immediate publication, while papers in the Annual Report were intended to be less technical in character, of general rather than special interest, and to include abstracts, in somewhat popular form, of monographic studies. It was found desirable, as time went on, to modify this plan, as it has been found wise to adhere not too strictly to that laid down for the conduct of the work itself. Thus, for a time the outside demands for economic surveys, solely on the secondary ground of their usefulness to those interested in mining in the special districts examined, increased very rapidly, while the force and funds at the disposal of the economic division were actually decreasing, so that the monographic treatment became unadvisable as a matter of policy, and the work was spread over a greater number of regions by devoting less time and labor to each.

In the latter part of the first decade and the first part of the second decade of the Survey's history, a very large proportion of the appropriation was devoted to the preparation of topographic maps, which serve as a basis for the work for which all geologic surveys are primarily organized. The making of a geologic map of so large an area as is included within the boundaries of our country is a far greater task than has been given to any previous Geological Survey. It is continental in its nature, and long deliberation and careful planning were required, before the actual publication could be entered upon, for the first essential is uniformity in all the parts, and therefore a plan once adopted should be carried out logically to its completion.

It was not until 1894 that the publication of the sheets of the Geologic Atlas of the United States in their final form of the "Geologic folio" was commenced. Over fifty of these folios have been now published, that is, at the present rate, about ten per annum. Owing to the great degree of accuracy required in the color-printing of these maps, their extreme complication, and the consequent necessity of personal supervision by the authors during the various processes involved, every part of this work, from the original drawing to the final printing and binding, is done in the Survey buildings. It was originally supposed that, with the present facilities for engraving and printing, the output would be twice as great as it is at present; but the advance in accuracy of geologic field-work, and the consequent increase in elaborateness of representation, have proceeded at a more rapid pace than has the growth of the means of publication.

Areal geologic mapping, as the work represented on folio sheets is designated, is always of economic importance, and probably over 90 per cent. of the areas for folios were chosen largely because of the value they would possess in the development of mineral resources.

A correct geologic map is the first and most essential basis for the study of a mining district; and where the deposits are beds in sedimentary strata, as is the case with coal, and sometimes with iron-ore and other substances, it furnishes practically all that the mining engineer needs for opening and exploiting the mines. By the folio publication, however, a new avenue is opened for disseminating geologic information promptly and without waiting for a final and exhaustive report. Where important groups of mines are concentrated within small areas, special maps of size to fit the folio are made of those areas, on the largest practicable scale, accompanied by sections and explanatory texts setting forth in concise terms the main facts of importance to the miner, and these are published as special folios, that is, folios that do not form an integral part of the regular Geologic Atlas of the United States. In this form there have already been published folios covering the Cripple Creek and Tenmile districts in Colorado, the Nevada City in California, and the Butte district in Montana. A folio of this form often supplements a monographic report, as it meets the demand of the mine-owner for more prompt

issue, and may be produced at smaller cost than a monograph. On the other hand, it is less likely to result in scientific deductions of general applicability, unless it is followed by a monographic report.

During the second decade of the Survey's existence, there has been a decided increase in economic work. One or more volumes of the Director's Annual Report are now devoted to papers of an economic nature, by which means more prompt publication and a wider distribution are secured for papers of this character. In this period five monographs and as many bulletins devoted to special mineral deposits have been issued, to say nothing of those indirectly bearing upon economic interests. Three of the five monographs treat of the iron ore-deposits of the Northwest, a preponderance that is explained by the fact that mine-owners in that region have themselves contributed many thousand dollars for the preparation of a topographic base for the work.

Another form of economic study, which may be called the *incidental economic survey*, and which has a very wide field in the future, is connected more directly with the folio publication. When the quadrangle that is being geologically mapped contains mines that are important, but not so near one another that they can be included in a special map, a trained economic geologist is detailed to make a special study of these mines, and a concise summary of the results is added to the explanatory text. If these results are of sufficient importance, a more complete report is printed in the Director's Annual Report, or as a bulletin. Such a study has already been made of the Telluride quadrangle, and similar studies of the Silverton quadrangle, in Colorado, and of the Sturgis and Spearfish quadrangles, in the northern Black Hills, are in progress.

It may be anticipated that in the course of time the incidental areal surveys and studies of special minerals will gradually supersede those of the small groups of important mines, but at present we have plans made for surveys of a dozen or more mining districts in the western portion of the United States, and of several in the central and eastern parts, which, under the present appropriations, can only be taken up one at a time and at considerable intervals.

Technical Investigation.—In the line of what may be consid-

ered technical studies, the duties of the Survey toward mining industry are less easy to define, for in this line there is more danger of encroaching upon the legitimate field of the mining engineer or metallurgist. Yet the same general principle is applicable here, namely, that the Survey should confine itself to those investigations which it is better fitted to make than is the individual. Thus, in our early work on Leadville, where lead-smelting had recently reached a stage of development hitherto unknown in this country, it was thought that a scientific discussion of the processes involved, in the light of the improvements made in practical methods, would be of advantage to the smelting community throughout the country. It was found, however, that so great was the commercial importance of the industry, and so rapid the advancement in metallurgic science, that the delays inherent in a Government publication greatly impaired, if they did not altogether nullify its value. Except in a few special cases, it has not, therefore, been thought advisable to follow out this line of work. Incidentally, as many are aware, the investigations of Dr Barus in the physical laboratory of the Survey on the iron carburets, although undertaken for purely scientific ends, have been of far-reaching practical importance to the iron industry of the country. This serves to illustrate the truth that, however remote from any apparent practical purpose a theoretic study may be, it is likely at any time to prove of practical scientific importance, and its application is broader, as a rule, than that of investigations which have only immediate practical ends in view.

It is evident that the investigation of technical processes in their commercial application is not a legitimate function of the Survey. Its employees are expressly shut out from a commercial use of their knowledge, and are chosen for their proficiency in geology rather than in technology. There may arise cases, however, in which it will appear possible for them to determine the underlying principles or laws that should govern some widely applied technical process, and in which it will seem advisable and proper for them to undertake such investigations.

Commercial or Statistical Investigations.—There remain to be considered the relations of the Survey to the purely *commercial side* of the mining industry, and here the principle of doing

what it is inherently better fitted to do than is the individual, is more easy of application. It seems evident that the collecting of accurate statistics of the mineral productions of the country, which form the most important basis of all mining business, is a prime duty of the Survey. No branch of statistical science is in greater need of technical knowledge and thorough system than that which deals with mineral production, and none is more liable to be led into error, if the collector's opinions are in any way biased by his interest. There is no body of men more absolutely disinterested than the employees of the Survey, since, under the law, they can have no commercial interest in the subjects which they treat. Their field of work is so wide that, by one or another, a certain personal familiarity with all the sources of supply of the various mineral products of the country is acquired, which is available for the guidance of the statistical division.

At the last session of the Fifty-fifth Congress an amendment was introduced establishing a Division of Mines and Mining in the Survey. This extended its sphere of statistical work to gold and silver, and made a special appropriation for the division. It also provided means for the more prompt publication of its reports. Had this amendment passed, it is believed that the scope of usefulness of the work of the Survey would have been very materially increased. All of its various economic branches would then have been conducted under the supervision of a single chief, by which means a more uniform and comprehensive system, both of field work and of publication, might have been inaugurated.

Statistics of Mineral Resources—The statistical work of the Tenth Census brought together such men as Emmons, Becker, Pumpelly, Peckham, Willis, Eldridge, and others who contributed to the volume on mining. Later, Mr. Albert Williams, Jr., was placed at the head of a division of the Survey created for the purpose of carrying out this work, and known as the Division of Mining Statistics and Technology.

Mr. Williams's plans were so well made that the results were excellent, and they admitted of simple expansion as the needs and facilities of the Survey made such expansion necessary and practicable. Mr. Williams's aim was to use the small means at his disposal to secure the co-operation of every individual and

institution for that particular contribution upon which he or it was the best authority. Primary attention was paid to locating and describing the known mineral localities, even down to those of rare elements. The work was arranged wisely, according to mineral substances rather than geographic regions, since each mineral industry was the interest intended to be served. This resulted in the series of publications called the "Mineral Resources of the United States." The first volume, published in 1883, contained, in addition to a statement of the distribution of our useful minerals, the best estimates obtainable of the total amount of each mineral produced in the year 1882, and comparative statements of the growth of each industry since the Census year—in so far as it could be predicted what the results of the Census would be when they should finally be published. The geographic distribution was not neglected, however, but was concisely set forth in a tabular statement showing the minerals which might prove useful in each district, and the volume contained also separate contributions on special themes of mining technology.

On this foundation a volume has been published each year since 1883. The second volume gave greater attention to the secondary feature of production and of our relations as mineral producers to the rest of the world, as shown by our import and export trade. The third volume was more limited in scope, being published in a transition-period, when Mr. Williams left the direction of the work to become Director of the Michigan Mining School and was succeeded by Dr. David T. Day.

These three volumes have certain characteristics which are not only interesting but deserving of attention, now that they can be looked at from a historical point of view. While the later volumes are probably better known, the three pioneer volumes were of unusual importance at the time they were published, when facilities were meager and guiding precedents few. They show the work of one whose careful judgment harmonized, when necessary, the diverse contributions of many co-workers. Each chapter was prepared by an expert. Each was a strong, terse expression of the conditions of the industry discussed. The chapters were as different in scope and in method of treatment as the materials themselves. Uniformity was neither possible nor desirable, but all were characterized by fair

statements of the measure of reliability to which the statistics were entitled.

Dr. Day, who has had charge of the succeeding volumes, came to the work with the prejudices of a technologist, but he left to the technologic press the subject of mining technology, except where some process had effected a significant development in mining. It seemed essential that the Survey should become a source of independent scientific statistics of the amount of each mineral produced, since no other agency than the Government can become the impartial and permanent source of reliable statistics, any more than we could expect coins to prove acceptable from other source than the Mint. By the advice of such census-experts as Gannett, Weeks and Swank, and with the co-operation of such statisticians as Kirchhoff, Birkinbine and Yale, every effort was made to secure a list of the mineral producers of the United States, and to obtain from each one of them, by correspondence and such visits as could be made, a statement of his product each year

The means at command were inadequate to a complete result; but each year has seen the lists grow more complete, and has shown less necessity for adding to returns by information from outside sources. The statistics of mining for the Eleventh Census were collected by the Survey. This experience added greatly to subsequent efficiency. At the present time the work is practically an annual census of the product of all mines, except those of precious metals. The statistics of gold and silver were excepted in the original plan, in 1882, out of courtesy to the Director of the Mint, who desired to retain in his own office this portion of the work

When the division abandoned the subject of mining technology, its designation was changed to the Division of Mineral Resources. In accordance with the duties implied by this title, more and more attention has been paid to statements of the geologic and geographic distribution of our mineral wealth, whether developed or not, and the immediate future will see this important work of the Survey expanded. Special subjects, studies of which are now in a more or less advanced stage of completion, are the phosphate-deposits of Florida, the clays of the Eastern States, bauxite in Arkansas, fuller's-earth in South Dakota, and the asphalts and bitumens of the whole United States

Hydrographic Investigations.—For more than ten years the Division of Hydrography of the Survey has been making measurements of streams and computations of their daily discharge at various points. At the same time, it has been investigating the movements of underground waters and the causes which give rise to them. The results have economic importance to the miner in his underground operations, as he must often contend with water, and his ability to dispose of it successfully may govern the question of profits. He often seeks in flowing water the power for operating, directly or indirectly, mines, mills, etc. In many sections the location of reduction-works is governed largely by the question of water-supply and its permanence through seasons and years. The results of the investigations of the hydrographers are sought in considering the erection of plants of this character.

There is also an indirect way in which the question of water-supply affects the feasibility or profits of mining. Throughout the western third of the United States, from the Rocky Mountain region westward, there are great deposits of ore, the value of which per ton is so small that they cannot be profitably worked unless many conditions are favorable, such as cheap foodstuffs and ready transportation, by which the cost of living and of labor may be reduced. The region as a whole is arid, and farm and other products, brought from the humid regions, are expensive. By the development of agriculture through irrigation, and the building up of small producing communities throughout the semi-arid and arid West, the cost of living is greatly reduced, and it becomes practicable to work to advantage mineral-deposits otherwise unprofitable. This dotting of the country with farms and villages is possible through a careful conservation of the available waters, such as can result only from a thorough knowledge of the natural conditions. This knowledge is being obtained, through the Division of Hydrography, as rapidly as the means available will permit.

FUTURE OF THE GEOLOGICAL SURVEY IN RELATION TO THE MINING INDUSTRY.

In considering the operations of the Survey, past, present and future, it must be borne in mind that all estimates for appropriations are submitted to the Secretary of the Interior,

who may reduce or change them as he thinks best, in view not only of the operations of the Survey, but of the needs of other bureaus of the Department and the sum total of the estimates. The estimates, and necessarily the plans, are, again, modified by Congress in making the appropriations. Special legislation is also occasionally needed in order to accomplish the best results in work already under way, or to enter some new field of investigation. Finally, after Congress has acted, all field- and office-plans of the Director, before being put into execution, are subject to the approval or disapproval of the Secretary of the Interior. To the practical miner and mining engineer all the red tape and delay seems only a useless hindrance to the development of the mining and other industries affected by the activities of the Survey. This is often the view of the men engaged in the work, but when a broad view of the entire field is taken, such delays and changes as may occur are of relatively small moment.

The work of surveying and preparing on a suitable scale the topographic and geologic maps of the 3,000,000 square miles of territory of the United States (exclusive of Alaska) is greater than any similar work heretofore undertaken by any nation. The study of the original sources of \$700,000,000 worth of mineral products each year, with the statistics pertaining thereto, is sufficient of itself to keep a bureau of the size of the Survey fully occupied. The investigation of water-powers, of artesian-, surface- and possible storage-waters, and of domestic water-supply, is an undertaking worthy of a strong, rapidly developing and rich nation. The publication in practical and creditable form of the product of all of the activities of the Survey results in a contribution in original maps and text larger than that of any other scientific organization in existence.

With such conceptions of the scope of operations in mind, and with the results of a decade of work and progress in view, individual and local disappointments and forebodings disappear. The results already attained by this single bureau of the Government form a monument to the intelligent interest taken in its work by Congress and the hearty support given it by the several Secretaries of the Interior. It is my belief, founded on years of experience, that the American people, as represented by Congress, desire to do what is right and just for govern-

mental scientific organizations Individual mistakes and narrowness of conception and action will occur at times, but as a whole the outlook is good, both for science and for the people of the nation.

I have been led to make the preceding observations because it has been not uncommon to hear and read criticism of Congress and of governmental methods of doing things Governments, like individuals, oftentimes learn and act slowly.

With these thoughts in view, let us consider the relations of the Government to the mining industry. For several years there has been a more or less active movement in progress to establish a Department of Mines and Mining. The latest bill on the subject, introduced by Mr J. A. Barham, of California, has many commendable features, but unless there is a decided change of sentiment in a future Congress, as compared with the last Congress, there will be nothing accomplished in this direction for some time to come. The function of the new Department, as defined in the bill, is "to acquire, by examination, practical and scientific experiments, geological research, or otherwise, useful information on subjects connected with mining in the general and comprehensive sense of the word, and to diffuse the same among the people of the United States." It is further provided that the Geological Survey shall be the nucleus of the new Department.

In the preceding pages an outline has been given of what has been and is being accomplished by the Survey. If the present bureau should be given authority to establish a division of mines and mining, with an appropriation for extending its mining and statistical investigations, all that the Barham bill provides for, as quoted above, would soon be an accomplished fact.

There is no doubt in my mind that the mining interests of the country are entitled to direct recognition by the government. If those interested in the mining industries wish such recognition, I would suggest that they first secure legislative provision for a division of mines and mining in the Geological Survey, and later, if it is found desirable, ask for the establishment of a Department of Mines and Mining. Meantime, pending decisive action, the Geological Survey will continue to aid, so far as practicable, in the development of the mineral resources and mining industries of the country.

Some Principles Controlling the Deposition of Ores.*

BY C R VAN HISE, MADISON, WIS

(Washington Meeting, February, 1900)

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PART I—GENERAL PRINCIPLES

INTRODUCTION.

THE following paper upon the principles controlling the deposition of ores is adapted from a treatise on Metamorphism, to be published hereafter as a Monograph of the United States Geological Survey. In the present paper the argument can be made only in outline. The argument is especially fragmentary in the treatment of the general principles controlling the circulation of underground water.

It will be held in this paper that the deposition of most ores is but a special case of the general work of groundwaters, of exceptional interest to man. In order to understand the special problem, it is necessary to have a profound knowledge of the general principles controlling the circulation and work of groundwaters. In the treatise from which this work is adapted I have attempted to treat this subject more fully and broadly than has heretofore been done. From this treatise so much is abstracted as seems absolutely necessary in order to understand the special application of the work of groundwaters to the genesis of ore-deposits. Where points are not covered with sufficient fullness, I beg the reader to suspend judgment until he sees the full treatise.

In the treatise, as well as in the following paper, I have of course drawn upon the knowledge contained in the writings of all previous workers. No general treatise upon a broad subject is the work of a single man. It is the conjoint product of all previous workers and its writer. In the following discussion of ore-deposits I am indebted to all who have contributed ideas to this subject, from the great Bischof to Sandberger and Posepny. I have tried to give full credit to all by numerous references, but I cannot be sure that I have done full justice in every case. A comparison with the writings of others will show that I am in accord with Prof. Joseph Le Conte upon more points than with any one else.*

Ore-deposits may be divided into three groups, viz · (A)

* *Trans Am Inst Min. Engineers*, vol. xxiv, p 996 "On the Genesis of Metalliferous Veins," by Jos Le Conte *Am. Journ Sci.*, 3d series, vol xxvi, 1883, p. 1 *et seq*

ores of direct igneous origin, (B) ores which are the direct result of the processes of sedimentation, and (C) ores which are deposited by underground water.

Ore-deposits of direct igneous origin are probably of limited extent. Certain very basic igneous rocks have been worked as iron-ores. In Norway are sulphide ores of various metals which Vogt* holds to be a direct segregation from a magma. Emmons† has also favored the idea of at least a first concentration of the metallic contents of ore by processes of differentiation from igneous rocks, more particularly basic ones. In many cases where ore-deposits, and especially sulphides are supposed to be igneous, the question may pertinently be asked as to how far aqueous agencies have worked in connection with the igneous agencies. I suspect, in most cases, that even if a first concentration has been accomplished by magmatic differentiation, that a second and more important concentration has been performed by underground waters, and this position I understand Emmons also to hold. Upon the question as to how far some ore-deposits are the direct processes of igneous agencies I do not propose here to enter.

To a limited extent ores are also the direct result of processes of sedimentation. As an instance of such ores may be mentioned some placer deposits. Possibly some ores are due to sublimation.

However, in so far as ores are of igneous origin, or are the direct result of the processes of sedimentation, or are the results of sublimation, they are excluded from the scope of the present paper. I intend here to consider only the third group of ores, —those produced through the agency of underground waters.

My first and fundamental premise is that the greater number of ore-deposits are the result of the work of underground water.

THE THREE ZONES OF THE LITHOSPHERE

In another place‡ I have shown that the outer part of the crust of the earth may be divided into three zones, depending

* J H L Vogt *Zeitschr für prakt Geol.*, Jan and Apr, 1893, Oct, 1894, Apr, Sept, Nov, Dec, 1895

† *Trans Am Inst Min Eng*, vol xxii, pp 53-95 "The Mines of Custer County, Colorado," by S F Emmons *17th Ann Rept U S Geol Surv*, part 11, 1895-96, pp 470-472

‡ "Principles of North American Pre-Cambrian Geology," by C R. Van Hise, *16th Ann. Rep U S. Geol Surv* for 1894-5, pt 1, p. 589 *et seq*, 1896.

upon the character of its deformation an upper zone of fracture, a lower zone of rock flowage, and a middle zone of combined fracture and flowage.

Zone of Fracture.

The zone of fracture is that near the surface. In this zone the rocks are not deformed mainly by flowage, but by fracture. They are adjusted to their new positions mainly by rupture and differential movements between the separated parts. When rocks are deformed in the zone of fracture the ruptures which occur are those of faulting, jointing, differential movements between the layers (or accommodation), fissility, and brecciation. The so-called folds in the zone of fracture are chiefly the result of numerous parallel joint-fractures across the strata with slight displacements at the joints, giving each block a slightly different position from the previous one, and thus as a whole making a fold. For instance, the folds of the rigid rocks in the Alleghenies are not in the main true flexures, but a series of slightly displaced blocks.

Zone of Flowage

In the zone of rock-flowage the deformation is by granulation or recrystallization, no openings being produced, or at least none except those of microscopic size *. This conclusion rests upon arguments which cannot here be fully repeated. However, it may be said in passing that the conclusion that a zone of rock-flowage exists at moderate depth is based, first, upon deduction from known physical principles as to the behavior of solid bodies under pressure, and second, upon observation. It is well known that when a rigid body, such as rock, is subjected to stress greater than its ultimate strength, it must rupture or flow. If a rock be subjected to a stress in a single direction greater than its ultimate strength in that direction, and the rock is not under pressure in other directions, rupture occurs. However, if we suppose that the rock be subjected to stresses greater than the ultimate strength of the rock in all directions, and that the difference in the stresses in different directions is greater than the ultimate strength of the rock

* "Principles," *cit*, p 594, *et seq*

under the conditions in which it exists, then if openings could be produced by a rupture, they would almost immediately be closed by pressure. In other words, at a certain depth below the surface of the earth, if we could suppose that cracks and crevices are formed by the deformation to which the rocks are subjected, the pressures in all directions being greater than the ultimate strength of the rock, these cracks and crevices would be almost immediately closed.

Since this conclusion was reached, Adams has actually deformed marble under the conditions supposed to exist at moderate depth below the earth, with the result that the rock changed its form without rupture and with no perceptible openings or cracks.*

Before the above inductive reasoning or Adams' experiment was made, I had become convinced from observation that at moderate depth rocks are deformed with fracture and differential movements between the solid particles (*granulation*), and by continuous solution and redeposition by underground water (*recrystallization*).† It was calculated that for all but the very strongest rocks, flowage must begin at a depth not greater than 12,000 meters,‡ for at this level the weight of the superincumbent mass is greater than the ultimate strength of the rocks.

Factors Influencing Depth at Which Flowage Occurs.—In the case of anticlinal arches a portion of the load may be removed by the supporting limbs, and thus the depth of the level at which the zone of flowage occurs beneath the arch be theoretically somewhat increased. However, it is highly probable that lateral stresses and increased temperature which always accompany rapid deformation, more than compensate for any removal of load. Time is another important factor. It is well known that a stress which in a short time is insufficient to rupture material may, if long continued, result in its deformation by flowage. The geologist has this factor, time, to a larger extent than scientists in any other subject, and it is a factor which he has con-

* Experiments in the flow of rocks are still being made at McGill University by Frank D Adams. A preliminary account was presented to the Geol. Soc. Am., Montreal meeting, 1897. This is summarized in "Science," vol. vii, 1898, pp. 82-83.

† "Metamorphism of Rocks and Rock Flowage," by C. R. Van Hise. *Bull. G. S. A.*, vol. ix, 1898, pp. 295-313, 318-326.

‡ "Principles," *cit.*, p. 592.

stantly to keep in mind. How important this factor is may be illustrated by the deformations of rocks as result of very moderate long-continued pressures. In some cases, in cemeteries, marble slabs have been placed horizontally and suspended at the ends. In the course of a score or more of years such slabs are found to have sagged in the middle a very considerable amount. If the slabs had at the outset been bent to this extent they would have undoubtedly been ruptured. The change in form is only possible by rock flowage, either through a differential movement of the solid particles with reference to one another or by solution and redeposition, *i.e.*, recrystallization, or the two combined. The consideration of time leads me to believe that the limit of 10,000 to 12,000 meters placed as the level at which flowage of the strong rocks must occur is probably too great, and observations upon deformation in the cores of mountain masses which have been deeply denuded confirm this conclusion. Rocks, even of the strongest kind, have in many instances been deformed by flowage rather than by fracture, when at depths much less than 10,000 meters.

Other factors, such as igneous intrusions or orogenic movements, increase the heat and pressure acting on the rock, and thus tend to diminish the depth at which flowage occurs.

If this reasoning is correct, it follows that all fissures must disappear at some depth, and that the maximum depth is limited by the depth of the zone of fracture for the strongest rocks

Zone of Combined Fracture and Flowage.

There is a zone of combined fracture and flowage below the zone of fracture, because rocks have varying strengths, because there is great variation in the rapidity of deformation, in the temperature at which the deformation occurs, in the moisture present, and in various other factors. A weak rock, for instance a shale, may be deformed by flowage at a much less depth than a strong rock, such as a granite. Thus the belt of combined fracture and flowage is of considerable thickness, possibly as thick as 5000 meters. In this zone we have all combinations of the phenomena of fracture in the various ways above mentioned, and of flowage by granulation and recrystallization

It is highly probable that the openings of the zone of fracture

gradually decrease in size as depth increases, until in the zone of flowage the openings are, as already explained, microscopic or non-existent. If a gradation such as indicated exists, it is a necessary corollary that the deformations of the zone of fracture must have their equivalents in the deeper seated zone of flowage and flexure. This point I have fully developed in other places.* It is explained that in depth faults are replaced by flexures, and that any deformation of a large mass of a given rock from one form to another by fracturing may be paralleled by similar changes of form in the zone of flowage, the result being there accomplished by granulation of the mineral particles or by recrystallization, or by both.

It might be thought that the above general statement is a deduction which cannot be confirmed by observation, but such is not the case. Many rocks which have been deformed in the zone of flowage or in the zone of combined fracture and flowage, as a consequence of denudation have reached the surface, and one is able to observe all the transition phenomena of deformation between the zones of fracture and flowage. These I have somewhat fully described in another place †. An excellent illustration of the deformation of a rock mainly by flowage, but in a subordinate way by fracture, is the Berlin rhyolite-gneiss, described by Samuel Weidman ‡. The formation of this rock was mainly that of recrystallization, but many of the mineral particles were granulated.* Also many minute joint crevices were formed which were subsequently filled by cementation.

It follows from the above reasoning that fissures may disappear at different depths below. Where there are fractures with large displacements, fissures are likely to extend to very considerable depths. In proportion as the displacements are small, the fissures are likely to disappear below at less depths. Furthermore, as has already been explained, certain rocks are deformed by flowage at a much less depth than are other rocks. Therefore, in a region in which there is a great shale

* "Principles," *cit*, p. 676, "Metamorphism," *cit*, pp. 313-318.

† "Principles," *cit*, pp. 601-603, "Metamorphism," *cit*, pp. 312-313.

‡ "A Contribution to the Geology of the Pre-Cambrian Igneous Rocks of the Fox River Valley, Wisconsin," by S. Weidman. *Bull. Wis. Geol. and Nat. Hist. Surv.*, No. III, pt. 2, 1898.

or slate formation at a moderate depth, a strong fissure in more brittle rocks at the surface may disappear as it encounters the shale formation, being replaced there by a flexure. I have little doubt that considerable fissures thus disappear at a depth less than 1000 meters

Illustrations of the disappearance of fissures with depth are found at various places. In the gold belt of the Sierra Nevadas, Lindgren* says it is "an incontestable fact that many small veins close up in depth."

Not only may fissures die out below, but fissures may disappear above, the fault along the fissures being replaced by a flexure in the overlying stratum, which yields by flowage. This is beautifully illustrated by the Enterprise mine, of Rico, Col., described by Rickard,† where faulted fissures in sandstone and limestone disappear above, at the place where shale is encountered, the shale accommodating itself to the fractures below by monoclinal flexures. (See Fig. 9, p 154)

The marked effect which the character of the country rock may have upon the nature of a fissure is well illustrated in the Cripple Creek district, where, according to Penrose,‡ the fissures in the hard rocks are sharp, clean-cut breaks, while in the soft rocks they are ordinarily a series of very small cracks, constituting a displacement of a kind which I call a distributive fault. Well illustrating this are mines which are partly in hard and partly in soft rock. "The vein on which the Buena Vista, Lee, Smuggler, and Victor mines are located occupies a sharp, clean-cut fissure, partly in the massive rock and partly in the hard breccia; but when it passes into the soft, tufaceous breccia on the east slope of Bull Hill the fissure is represented only by faint cracks occupied by no vein of importance. In this case the force which caused the fissure overcame the cohesion of the harder rock sufficiently to make a clean break, but in the more plastic rock it overcame cohesion only to the

* "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann Rept U. S. Geol Surv*, pt. II., 1895-96, p 162

† "The Enterprise Mine, Rico, Col.," by T. A. Rickard, *Trans Am Inst Min Engineers*, vol. XXVI, 1897, pp 906-980

‡ "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr. *16th Ann Rept U S Geol Surv*, pt. II, 1894-95, p 144

extent of causing a series of faint fractures without any one well-defined break "*"

This point of transition between the zone of fracture and the zone of flowage and the dying out of fissures below is dwelt upon in order to exclude the hypothesis of filling of fissures from the bottom. If fissures gradually decrease in size and finally die out, the streams which make their way into the fissure must enter from the side or from above. For further development of this point, see pp. 80-82.

In closing the subject it may be said that in all cases where rocks have been deformed in the zone of rock flowage, or in the zone of combined fracture and flowage, and are now at the surface, there will be superimposed, upon the effects of the deep-seated deformation, the deformation by fracture, resulting from earth movements during the time the rock is slowly migrating through the zone of fracture to the surface.

THE WATER-CONTENT AND OPENINGS IN ROCKS.

Since the ore-deposits considered in this paper are the work of underground water, and since the flowage of underground water is mainly through the openings in rocks, it is necessary to consider the condition of the water in the openings and the character of the openings which may occur in rocks.

As to the content of water the zone of fracture may be divided into two belts, an upper belt above the level of groundwater called the belt of weathering and a lower belt below the level of groundwater called the belt of saturation. Above the level of groundwater the openings in the rocks are ordinarily only partly filled with liquid. Under different conditions, which need not here be discussed, the water in the openings varies from an exceedingly small fraction of that required to fill the openings, to saturation.

Condition of Water in the Zone of Fracture.

In the belt of saturation, from the level of groundwater to its base, if it be limited to a depth of 10,000 meters, the H_2O is in liquid form, as water. The water is, however, for much of the belt superheated. If the increment of increase of tempera-

* *Loc. cit.*, p. 144

ture be taken as 1°C for every 30 meters, the critical temperature of water, 364°C , would be found at a depth of 10,920 meters. At any given place the water is subject to the pressure of the superincumbent column. The question, whether hydrostatic pressure increases at a rate sufficient to prevent the vaporization of the water, must be answered.

If the temperature of the water were 100°C , or just at the boiling-point at the surface of the earth, the most unfavorable assumption to holding the water as a liquid in the zone of fracture, it would still be true that the water would be in the form of liquid in this zone, as is shown by the following table based upon this supposition, column (1) being temperatures, column (2) being pressures necessary to hold H_2O as a liquid at these temperatures, column (3) being depth in meters at which the pressures would be produced, column (4) being the depth which would be required to produce the temperatures on the supposition that the increment of the increase of temperature is 1°C . for every 30 meters, and column (5) being the actual temperatures which exist upon this supposition at the depths represented by column (3).

(1) Temperatures (100°C at Surface)	(2) Pressures Corresponding to Temperature of Col 1	(3) Depth Necessary to Produce Pressure of Col 2	(4) Depth Necessary to Produce Temperature of Col 1	(5) Temperatures Actually Existing at Pressures and Depths of Cols 2 and 3
Deg C	Atm	Meters	Meters	Deg C
120	2	20	600	100 66
180	10	100	2,400	103 33
225	25	250	3,750	108 33
265	51	510	4,950	117 00
310	99	990	6,300	133 00
340	148	1,480	7,200	149 33
365	205 5	2,055	7,950	168 33

From this table it will be seen that the hydrostatic pressure at various depths is far in excess of that required to hold the water in the form of a liquid, or, looked at in another way, for any given depth the temperature is not sufficiently high to allow the water at that depth and pressure to exist in the form of a gas.

Therefore, where the increase of temperature is normal, the pressure at any point down to the level at which the critical

temperature of water is met is clearly much more than adequate to prevent the water from changing to steam. Where magma is intruded in the lithosphere, the temperature may become so high that this statement will not hold. This, however, is the exceptional, not the usual, case. Furthermore, it is conceivable that as result of deformation itself the temperature of the rocks might rise so high as to convert the water present into the form of steam. This possibility will not be discussed. However, it is believed to be probable from investigations upon metamorphism that this condition of affairs rarely if ever obtains, since, as I have elsewhere explained, long before the critical temperature of water is reached, solution and deposition of rock material, or recrystallization, readily takes place, and in this change the work converted into heat is far less than in mechanical granulation.*

The Openings in Rocks.

The openings in rocks include (1) those which are of great length and depth, as compared with their width, and thus are essentially flat parallelipeds; (2) those in which the dimensions of the cross-sections of the openings are approximately the same, and therefore resemble tubes of various kinds, and (3) irregular openings

(1) The openings of the first kind are those of faults, of joints, of fissility, and of bedding partings. The openings of this class are likely to be continuous for considerable distances. This is true to the largest extent of fault openings, is true to a less extent of joint openings and bedding partings, and to a still less extent of the openings of fissility. It is recognized that many of the fissures are exceedingly complex. They are, indeed, in many instances, a series of parallel or intersecting fractures, forming a zone of brecciation. However, for such a zone, as a whole, the statement still holds that the openings have great length and depth as compared with their width. In position, the joint-, fault-, and fissility-openings ordinarily have an important vertical element, or at least traverse the beds. Frequently they are nearly vertical, or traverse layers of formations at right angles. In consequence of this, they are very important factors

* "Metamorphism of Rocks and Rock Flowage," by C. R. Van Hise, *Bull. G. S. A.*, vol. ix, 1898, pp. 310-311, 313-318.

in the flowage of underground water. Relatively pervious formations separated by impervious formations may be thus connected. Pervious formations overlain by impervious formations may be connected with the surface. Bedding-partings are parallel to the layers. Since underground waters very frequently follow formations, the bedding-partings, which extend long distances, become very important factors in the promotion of flowage parallel to the formations. This is especially true of the contact of formations of different character. These contacts are places of maximum differential movements, of consequent complex fracturing, and therefore of important openings and large circulation.

(2) The spaces of the second class are those of the mechanical sediments, including conglomerates, sandstones, soils, tuffs, etc. The openings of mechanical sediments have a strong tendency to a definite form, and are continuous. The forms of these openings have been fully discussed by Slichter.* The openings alternately narrow and widen. At their wider parts their sections are roughly polygonal, the polygons having more than three sides, and these are curved. At their narrowest places, the cross-sections of the openings approximate to triangles, and where the grains are of equal size, the triangles are equilateral. The form of the tubes at their minimum cross-section is due to the contact of three grains in a plane, the space between which is nearly triangular.

(3) Irregular openings are those of the vesicular lavas and the irregular fractures of the rocks. They are in part continuous and in part discontinuous. In rocks where the openings are exceedingly irregular in form, the flowage of water is limited to the continuous openings, however small they may be.

Openings of any of the above classes, whether a result of deformation or produced by original sedimentation or formed in connection with volcanic action, may be enlarged by solution. Indeed, this will be the case wherever the processes of solution more than counterbalance the processes of precipitation. It is later explained that this is the more likely to occur with downward moving water than with upward moving water. Since

* "Theoretical Investigation of the Motion of Ground Waters," by C. S. Slichter, 19th Ann. Rept. U. S. Geol. Surv., for 1897-98, pt. 11, pp. 305-323.

downward moving waters are dominant above the level of groundwater and prominent in the upper part of the belt of saturation, it is in this area that openings are most frequently enlarged by solution (See pp. 72-74, 158) It has been argued by Posepny* that openings serving as channels for underground water may be wholly produced by solution. That openings may be somewhat prolonged and different openings connected by solution, thus helping underground circulation, is more than probable, but that important passages are produced wholly by solution is an assumption which I think has not been verified by the facts of observation.

Size and Number of Openings.—Large openings are favorable to rapid flowage. Small openings are unfavorable to rapid flowage. This results from the fact that the friction between the walls and the moving column steadily becomes greater for a given volume of water as the openings become smaller. Large openings are favorable to a somewhat direct course. Small openings are favorable to a circuitous route. The direct course of water in large openings is illustrated by limestone regions, where there are numerous large joints and caves within which the water is quickly concentrated. This being the case, the flowage of water is very largely in the upper part of the zone of fracture. Where the openings are small, a circuitous route must be taken, for to pass a given volume of water from one point to another it is necessary that a wide range of openings must be used. This is more fully explained, pp. 54-62

Fault, joint, bedding, and fissility openings may be so numerous that the pore-space is very large. Upon the average fault openings are farther apart, but larger than the joint openings, and joint openings are wider spaced and larger than the openings of fissility. It cannot be said which kind of openings upon the average gives the larger pore-space. Since, however, large openings are favorable to rapid flowage, for a given pore-space the fault openings are likely to give a greater flowage than joint openings, and joint openings a greater flowage than those of fissility. This follows from the greater size of the fewer openings. To this is to be added the element of greater

* "The Genesis of Ore-Deposits," by F. Posepny, *Trans. Am. Inst. Min. Engineers*, vol. xxiii., 1894, pp. 207-212

continuity of the larger openings. Therefore, with a given pore-space, the flowage may be vastly greater in the case of faults than in the case of joints, and much greater in the case of joints than in the case of fissility. It will later be explained that the larger openings are occupied by the trunk streams, and that in these openings ores are most likely to be concentrated; hence, ore-deposits most frequently form in fault-fissures, less frequently in joints, and still less frequently in the smaller and more discontinuous openings.

If the principle that large openings are favorable to rapid flowage be applied to mechanical sediments, it follows that with a given pore-space the coarse conglomerates furnish a much larger flow than fine conglomerates, the fine conglomerates a larger flow than the sandstones, and these a vastly larger flow than the fine-grained shales.

Upon the basis of size, openings in rocks may be divided into (a) openings which are larger than those of capillary size, or supercapillary openings, (b) capillary openings, and (c) sub-capillary openings.

For water, openings larger than capillary openings, according to Daniell,* may be circular tubes which exceed .508 mm. in diameter, or may be sheet-openings, such as those furnished by faults, joints, etc., whose widths are one-half of this or exceed .254 mm. To movement of water in such openings the ordinary laws of hydrostatics apply. Capillary openings for water solutions include those which, if circular tubes, are smaller than .508 mm. in diameter, or, if sheet spaces, are narrower than .254 mm., and which in either case are larger than the openings in which the molecular attractions of the solid material extend across the space. Such openings in the case of circular tubes are those smaller than .0002 mm. in diameter, or, if sheet passages, are below .0001 mm. in width. Capillary openings therefore include circular tubes from .508 mm. in diameter to .0002 mm. in diameter, and sheet passages from .254 mm. in width to those .0001 mm. in width. Capillary openings of other forms have a range limited between .508 mm. and .0001 mm., but no one form has so wide a range as this. To movement of water in openings such as these the laws of cap-

* *Text-Book of Physics*, by Alfred Daniell, 3d ed., 1894, pp. 277, 316

illary flow apply. By subcapillary openings are meant those in which the attraction of the solid molecules extends from wall to wall. These include all tubes smaller than .0002 mm. in diameter, and sheet openings smaller than .0001 mm. in width. For intermediate forms the subcapillary openings have as their maximum limit a range from .0002 mm to .0001 mm

Within this paper I cannot fully discuss the laws of flowage for each of these classes of openings and their application. This is fully done in a treatise on "Metamorphism," from which this paper is abstracted. It is, however, necessary to summarize the laws of flowage of water in each of the three classes of openings.

The flowage of water through supercapillary tubes nearly follows the ordinary laws of hydrostatics, *ie*, the flowage of water is as the square root of the pressure due to head. If V = velocity, H = pressure due to head, and G = force of gravity, then $V = \sqrt{2GH}$. For instance, the velocity resulting from a head of 10 cm would be the square root of $2 \times 981 \times 10$ cm.

This formula is only approximately correct, for the internal friction in supercapillary tubes is dependent upon the viscosity of the solutions (a factor considered on p 56), upon the regularity of the tubes, and upon the velocity of flowage. If the tubes are not straight, eddies will form which will increase the internal friction and decrease the speed of movement. In the long, rough, irregular underground passages not of determinable size, eddies may so increase the internal friction as to render the formula of hydrostatic flow inapplicable. Further, as a result of the viscosity, the resistance increases with increase of velocity, so that where the velocity of movement is considerable, even if the tubes are open and continuous, the formula gives too high results.

The flowage of water with a given head in supercapillary openings is very rapid indeed, as compared with the smaller openings. The supercapillary openings include the greater number of the fault openings, joint openings, bedding partings, many openings of fissility, and the openings in the coarser mechanical sediments, such as very coarse sandstones, and conglomerates.

According to Poiseuille's law, the flowage of water in capil-

lary openings is proportional not to the square, as in supercapillary openings, but to the fourth power of the radius; is proportional not to the square root of the pressure, as in supercapillary openings, but to the pressure; is inversely proportional to the length of the tube, and is indirectly proportional to the viscosity of the liquid *

From the foregoing it follows that the flow in a tube with a radius of 2 mm in diameter would be sixteen times as great as in a tube 1 mm in diameter. Furthermore, in a tube of a definite length, if the pressure be doubled the flow would be doubled, if trebled the flow be trebled. With a given pressure, if the length be doubled the flow would be diminished to one-half, if trebled to one-third. The viscosity of underground waters decreases rapidly with the temperature, being only one-fifth as much at 90° C. as at 0° C. Therefore, with capillary tubes of a given size the flowage would be five times as fast at 90° C. as at 0° C.

How important the laws of capillary flow are in the movement of underground water and the production of ore-deposits will be understood when it is known that the openings of all ordinary sandstones and mechanical sediments are capillary openings. Furthermore, it is to be remembered that at a depth of 2700 meters, supposing the increment to be 1° C. for 30 meters, the temperature is 90° C. Therefore this fact, because of decreased viscosity, is very favorable to the flowage through the openings at considerable depth.

Notwithstanding the increased mobility of water, the circulation in small capillary tubes is very slow indeed, so slow that layers of rocks in which the openings are of small capillary size, such as those of dense clays and shales, are spoken of as impervious. Although this is not exactly true, the movements of water through such materials is slow as compared with the movement in larger capillary openings.

Openings of the third class are subcapillary. In these the

According to Poiseuille, the general formula for the flow through a tube of circular section is $f = \frac{a^4 p}{8 \mu l}$, in which f is the discharge in cubic centimeters per second, a is the radius of the tube, l its length, p is the difference in pressure at its ends in dynes per square centimeter, and μ is the coefficient of viscosity of the liquid (See "Theoretical Investigation of the Motion of Ground Waters," by C. S. Slichter, *19th Ann. Rep. U. S. Geol. Surv.*, pt. 11, p. 317.)

attraction of the solid molecules extends from wall to wall. The water is held as a film glued to the walls by the adhesion between the water and rock. There is no free water. In such openings as these the flowage must be exceedingly slow or nil. Subcapillary openings as here used include also intermolecular spaces.

It is evident, from the reasoning given on the preceding pages, that the openings in the zone of rock-flowage are those of subcapillary size. Furthermore, it is evident that the subcapillary openings are discontinuous. It has been seen that at a depth greater than about 11,000 meters the water probably has a temperature greater than the critical temperature of water, but in the opinion of some physicists the liquid state may persist even after the critical temperature be passed.* Whether the H_2O below this depth is a liquid or is water-gas cannot certainly be determined; but it may be supposed that the viscosity is comparatively small. Furthermore, the water is under enormous pressures. Under circumstances of temperature exceeding the critical temperature of water and very great pressure, one would be rash to assert that water does not pass through the exceedingly small subcapillary spaces of rocks in the zone of flowage, or possibly also through the intermolecular spaces. Some movement of water might also occur in connection with the processes of solution and deposition, or recrystallization, which, as I have explained, is characteristic of this zone. That is to say, the mobility within the solid material implies at least an equal mobility in the liquid material which is also present.

In reaching a probable conclusion it is, however, to be remembered that it must be assumed that the rocks of the lower part of the lithosphere are also probably saturated with water, and that the pressure above is resisted by equal pressure from below. Doubtless, under the changing conditions caused by rock deformation, metamorphism and denudation, and by other vicissitudes to which the lower part of the lithosphere is subjected, the water-pressures become unequal at various times and places, and at such times and places there would be an undoubted tendency for water to move from places of great pressure to places of less pressure.

* Preston, "Theory of Heat," p. 378.

Whatever conclusion may be reached as to the possibility of the circulation of water in the zone of rock-flowage, it will probably be agreed by all that the circulation, if it occurs at all, must be exceedingly slow. Indeed, upon this point we are not confined to deduction. We have an almost certain inference from the character of the alterations which occur in the zone of rock-flowage. In my treatise on Metamorphism I show that within the zone of fracture, immigration and emigration of rock-material is very great, and that the composition of a rock may within this zone be materially modified as a consequence. However, while a rock in the zone of flowage may be transformed from a massive form to a schist or a gneiss, the composition of the resultant schist or gneiss is almost identical with that of the original rock. Had there been rapid and extensive circulation of water within this belt, it would have been inevitable that the composition of the resultant metamorphosed rocks would have been different.

Ore-Deposits Derived from Zone of Fracture.

We conclude from the foregoing that while underground circulation of water upward, downward, and lateral, is a possibility within the zone of rock-flowage, it is very slow, and that it cannot be appealed to to explain metalliferous deposits. If any one asserts that the metalliferous materials of mineral veins are derived by water circulation from the centrosphere,* or are derived from the lithosphere* below the zone of rock-fracture, I hold this to be a pure unverified assumption for which there has not as yet been adduced one particle of evidence, and opposed to which stand well-known principles of physics concerning the movement of water in minute openings, and all observations which have been made as to the actual changes which have taken place in the rocks once within the zone of rock-flowage.

The original source of much of the material for the metalliferous deposits may, indeed, be largely the centrosphere or the lower part of the lithosphere; for from these sources vast masses

* The term lithosphere is here applied to the outer shell of earth, which is known to be solid. The term centrosphere, following Powell, is applied to the central mass within the lithosphere comprising the greater part of the world, as to the character of which we have no definite knowledge.

of volcanic rock are injected into the zone of fracture or brought to the surface. This is especially true during great periods of vulcanism. Furthermore, it is well known that in regions of volcanic rocks many ore-deposits are found. Also it is believed that all the rocks of the lithosphere were originally igneous, and that from these igneous rocks the sedimentary rocks have been derived by the epigene forces, *i.e.*, the forces working through the agencies of atmosphere and hydrosphere. It follows, therefore, that the metals of ore-deposits, either directly or indirectly, are derived from igneous rocks. However, the ores are directly derived from rocks in the zone of fracture by circulating underground waters. The rocks which furnish the metallic compounds may be intruded igneous rocks, they may be extruded igneous rocks; they may be the original rocks of the earth's crust, they may be sedimentary rocks derived by any of the processes of erosion from primary rocks; they may be the altered equivalents of any of these classes

That there is a sufficient amount of metalliferous material within the rocks of the zone of fracture to account for all metallic deposits will be admitted by all. It is well known that the amount of material which it is necessary to suppose to be originally present in the country-rock within the reach of the underground water circulation in the zone of fracture, in order to fully account for the ore-deposits, is an exceedingly small fraction of 1 per cent; such small fractions in the case of the rarer metals that the numbers have little significance to us. Even in the case of the common metals, such as iron, lead, zinc and copper, the fraction of a per cent. which it is necessary to suppose to be present is exceedingly small. This is well illustrated by the lead- and zinc-district of southwestern Wisconsin. Here, according to Prof. Chamberlin, Mr. Buell has calculated that if the source of the metal in the Potosi district, the richest in the region, be restricted to a layer 100 feet deep and limited on the outside of the area of paying crevices by half the average distance between the crevices, to account for all the lead which had been taken out, it would only be necessary to suppose that the rock contained "one-fourteen-hundredth of one per cent., or a little more than seven millionths part of the rock."*

* "Ore-Deposits in Southwestern Wisconsin," by T. C. Chamberlin, *Geol. of Wis.*, vol. 17, 1882, pt. 17, p. 538.

The second fundamental premise of this paper is, that the material for ore-deposits is derived from rocks within the zone of fracture.

The Source of Underground Water

Since it has been shown it cannot be assumed that there is any considerable circulation of underground water in the zone of rock-flowage, it follows that we cannot suppose that the water of the zone of fracture passes into or is derived from the zone of rock-flowage on any large scale. Doubtless this transfer does take place to some small extent. Also, through the agency of vulcanism water occluded in magma is transferred from the zone of rock-flowage, or even possibly from the centrosphere, to the zone of rock-fracture. Furthermore, hydration and dehydration of the rocks are constantly taking place, and these processes may not balance. However, the amount of underground water coming from the deep-seated zone of rock-flowage in these ways at any one time is relatively small, and therefore the meteoric water entering the crust substantially balances that issuing from it. Hence, so far as the main work of ore-deposition is concerned, the water is that of the zone of rock-fracture, and this water is water of meteoric origin, which makes its way from the surface into the ground, and there performs its work and issues to the surface again.

The third premise of this paper is that by far the major part of the water depositing ores is meteoric.

The Cause of the Flowage of Underground Water.

The fourth premise of this paper is, that the flowage of underground water is caused chiefly by gravitative stress.

Gravity is effective in the movement of underground water in proportion to the head. Head is due to the fact that the water entering the ground at a certain level, after a short or long underground journey, issues at a lower level.

The efficiency of gravity is also dependent upon temperature. In so far as water is warmer at its point of issuance than it was when it joined the sea of underground water, this is favorable to circulation, and gives an effect in the same direction as head. This is due to the fact that the density of water varies inversely with the temperature.

Taking the volume of water at 4° C. as 1, its volume at 50°

C. would be 1.0120, at 75° C would be 1.0258, and at 100° C. would be 1.0432 * Therefore the increase in the temperature of underground water may lessen its density as much as 4 per cent without exceeding its boiling-point at normal pressure, and a diminution of density of 1 per cent or more is probably not uncommon. It is therefore evident that in columns of water of equal length the stress of gravity is considerably greater upon the column having the lower temperature. That the difference in gravitative stress, due to difference in temperature, may be sufficient to produce rapid circulation in pipes which are supercapillary, is shown by the use of the principle in the hot-water system of heating buildings. Underground, as in the hot-water system of heating, heat is the energy which causes the water to expand, and gives a difference in density. When heat has produced a difference in density of the two columns, gravity is the force which inaugurates and maintains the circulation.

It is believed that underground circulation may be promoted in an important degree by difference in temperature of the descending and ascending columns of water, resulting from heat abstracted from the rocks, due wholly to their normal increment of temperature with depth. Later it will be shown that the downward moving water is ordinarily dispersed in many small openings and moves relatively slowly. Therefore it may be supposed at any given place to have approximately the temperature of the rocks. The upward movement of water, upon the contrary, is shown to be usually in the larger openings and relatively rapid. Therefore at any given place its temperature is probably higher than is normal for the rocks at that depth. The result is to give the descending and ascending columns a difference in temperature, the ascending column being hotter. As already noted, the expansion of water with increase of temperature is considerable, amounting to over 4 per cent between 0° C and 100° C., that is, a given mass of water would occupy a volume 4 per cent. greater. In other words, if there is an average difference of 100° C. in the ascending and descending columns, 100 feet of the downward moving

* "Exercises in Physical Measurements," by L. W. Austin and C. B. Thwing 1896, p. 151.

water would balance 104 feet of the upward moving water. If we suppose the descending and ascending columns to be connected, of equal height, and having an average difference of 100°C in temperature, this would be equivalent to a head of 4 feet per 100 feet all along the length of the column. Probably the difference in temperature between the columns is not often so great as 100°C , but the illustration shows that the difference in temperature between ascending and descending columns of the same length may give a sufficient stress to overcome friction and viscosity, and give a somewhat rapid movement to underground water.

As an illustration of the principle may be mentioned the water-power of the sea-mills of Cephalonia, which, according to the Crosbys, is wholly due to the difference in the temperature of the descending and ascending waters*. In regions where vulcanism or dynamic action has recently occurred, the difference in density resulting from difference in temperature in the descending and ascending columns may be an even more important influence in the circulation of the underground waters than in regions where the high temperature is due to the normal heat of the rocks. Such a region is the Yellowstone Park

In some cases the issuing water throughout a great region is very clearly at a higher temperature than the entering water, and in such regions this difference in temperature must be a very important factor in its underground circulation. In such cases the difference in temperature of the descending and ascending waters generally results from the normal increase of temperature due to depth, from regional vulcanism, and from the rocks having a higher temperature than normal because of recent orogenic movements.

An excellent illustration of such a region is the Cordilleran region of the western United States, in which there are many valuable ore-deposits. Gilbert† and others have shown that scattered throughout this vast region, occupying nearly one-

* "The Sea-Mills of Cephalonia," by W F Crosby and W O Crosby, *Tech. Quar*, vol ix, 1896, pp 6-23

† "The Geology of Portions of Nevada, Utah, California and Arizona, Examined in the years 1871 and 1872," by G K Gilbert, *Rept. Geog. and Geol. Surveys west of 100th Meridian*, vol. iii, 1873, pt 1, pp 148-149.

third of the United States, are many hot springs, the temperatures of which vary from 37°C to 100°C . More numerous than these are the warm springs, the temperatures of which are below blood heat. The warm springs may be considered as including those between 18°C and 37°C . According to Gilbert, the water of all the foregoing springs exceeds the mean annual temperature of the region by 8.3°C .

Although we have no data by which to verify the statement, I have no doubt whatever that the springs, the temperature of which is above the mean annual temperature, but less than 8.3°C above, exceed by many times the total of all springs the temperatures of which are 8.3°C or more above the normal temperature of the region. And it is to be remembered that a slightly increased temperature of issuing water over that of the falling water through the vast number of springs and through seepage is of far greater quantitative importance than the marked increase of temperature in the comparatively few warm and hot springs. This illustrates the old principle that the widespread, moderate forces are incomparably more important than the more conspicuous, but more circumscribed forces.

While gravity is the only important force to which appeal can be made to account for the circulation of waters producing ore-deposits, circulation in some small degree does result from other immediate causes. For instance, earth movements may deform the rocks, and in this process squeeze out the water, as in the production of the crystalline schists from the sedimentary rocks. If the deformation of the rocks be referred to their ultimate cause, gravity, even the circulation of the water resulting from deformation is indirectly due to the stress of gravity. However, the important immediate causes of movements of underground water below water level are two—gravity and deformation.

But whatever the cause of the flow of underground water, the direction of movement is from places of greater pressure to places of less pressure. A current going in any direction is evidence of an excess of pressure in the rear of the current. Thus, water which enters by seepage or through capillary tubes into a larger opening, such as a fissure, must be under greater pressure than the column of water into which it makes its

way Whether the motive force in the movement of the water is difference in gravitative stress or deformation, or any other cause, the excess of pressure resulting in movement is behind the current.

In the foregoing statement as to the cause of the movement of underground water, only the vertical component of the columns has been considered The horizontal component of the column has no effect So far as there is horizontal movement, the energy required for this movement to overcome friction and internal viscosity is derived from the forces already mentioned,—that is, gravitative stress or deformation.

Belts of Underground Circulation.

The circulation of underground water is divided into two parts that of an upper belt above the level of groundwater, and a lower belt below the level of groundwater

Upper Belt of Underground Circulation—The upper belt of underground water circulation extends from the surface to the level of groundwater The thickness of this outer belt of water circulation varies greatly. At or near streams, lakes, or ocean, and in areas where the surface is not much higher than the adjacent bodies of water, the level of groundwater may reach near or to the surface, and thus there may be, for these areas, either a very thin upper belt of circulation, or none. In regions of moderate elevation and moderate irregularities of topography the level of groundwater is usually from 10 feet to 100 feet below the surface. It is especially likely to be near the surface in regions where there is a thick layer of drift or a thick layer of disintegrated rocks. In elevated and irregular regions, and especially those in which the precipitation is rather small, the level of groundwater may be from 100 to 300 feet below the surface In high, desert regions, and especially limestone regions, the level of groundwater may be from a thousand to several thousand feet below the surface.

The position of the level of groundwater is more fully considered further on, in connection with the belt below that level

A large amount of the water which enters the upper belt is, without entering the lower belt, again brought to the surface through capillarity, or through the influence of vegetation. The circulation of this water in the upper belt alone has little

influence upon the ore-deposits, and is here ignored. Another portion of the groundwater moves downward through the upper belt and joins the sea of underground water. This water is associated with oxygen, carbon-dioxide, and other gases. These substances perform various classes of work, which are considered on pp 74-79.

Lower Belt of Underground Circulation—The lower belt of circulation has as its upper limit the level of groundwater. This level is not horizontal, but is undulating, the undulations following the topography. A topographic map of a region is to a certain extent a topographic map of the level of groundwater, but the latter is less accentuated. The elevation of the contour of the groundwater at a given place is less than the elevation of the surface contour by the depth of the level of groundwater.

That the level of groundwater roughly follows the topography is shown by the fact that upon many hills and mountains, wells reach water at the very moderate depths of a few score, or at most 100 or 200 feet. The relation is further illustrated by the fact that where a shore begins to rise from a body of water, as from a lake, the level of groundwater also rises, but not so rapidly. As an example of this may be mentioned the case of a well at Madison, Wisconsin, about 1200 feet from Lake Mendota and 88 feet above its surface, in which the water is on an average about 52 feet above the surface of the lake*.

In general, the more accentuated the topographic features, the greater is the difference between the surface topography and that of the level of groundwater. However, this difference also depends upon the character of the rocks. Where the openings in the rocks are numerous and large, there is a greater difference in the topography of the surface and of the level of the groundwater than where the rocks are less open. In fractured limestone regions containing caves, the level of the groundwater may follow approximately that of the drainage of the district, and thus there be a great difference between the topography of the surface and that of the groundwater. Where a region is covered with a thick mantle of fine material, as drift,

* "Principles and Conditions of Movements of Groundwater," by F. H. King, 19th Annual Rept U S Geol Surv, for 1897-98, pt II., p. 99, 1899.

the topography of the groundwater may very closely follow that of the surface. Finally, the less the precipitation the greater the difference between the contours of the surface and the level of groundwater. In the Grand Cañon region of Colorado we have a district in which the topography is much accentuated with sudden and great changes in elevation, in which the rocks are largely limestone and the precipitation small. Therefore in this region there is a very great difference between the topography of the surface and that of the level of groundwater.

Capacity of Water for Work in the Lower Belt of Underground Circulation.—The temperature of water in the lower belt of underground circulation increases with depth. The average increment is about 1°C for 30 meters. Supposing the water at the surface to be 0°C , it would be 100°C . at a depth of 3000 meters. At a depth of 10,000 meters it would be 333°C . It has been shown, pp. 36–38, that the pressure increases with depth with sufficient rapidity to hold the water in the form of a liquid. Therefore the work of the water in the zone of fracture below 3000 meters is that of superheated water. It is well known that pure water at ordinary temperatures is capable of dissolving all compounds to some extent, but the amount of the more refractory compounds dissolved is exceedingly small. But pure water at a high temperature is a potent solvent. Barus has shown that water at temperatures above 185°C attacks the silicates composing soft glass with astonishing rapidity *

At 180°C . various zeolites can be dissolved in pure water, the material crystallizing out on cooling. Lemberg shows that water at 210°C . slowly dissolved anhydrous powdered silicates. It is therefore apparent that water in the lower part of the zone of fracture is a most potent chemical agent

Furthermore, it is well known that one salt in solution may assist water in dissolving another salt. For instance, the presence of alkaline sulphides is very favorable to solution of sulphides of the heavy metals, such as copper, silver and gold. On the other hand, the presence of one compound in solution

* "Hot Water and Soft Glass in their Thermo-dynamic Relations, by C. Barus, *Am. Jour. Sci.*, IV., vol. ix, 1900, pp. 161–175.

may be unfavorable to the solution of another compound. Thus in the underground waters the material in solution continually affects the capacity of the water to dissolve and precipitate other materials. This subject will be further discussed, pp 69-71.

Movements of Water in the Lower Belt of Underground Circulation—The complex movements of underground water may be resolved into two components, horizontal or lateral movements and vertical movements.

The vertical component of the journey of underground waters in the zone below the level of groundwater may be considered as confined to the zone of fracture, and is probably measured at a maximum by 10,000 meters, or at most by 12,000 meters. The lateral component, on the other hand, may vary from a few meters to hundreds or even a thousand or more kilometers. Upon the average, the horizontal component is probably far greater than the vertical component.

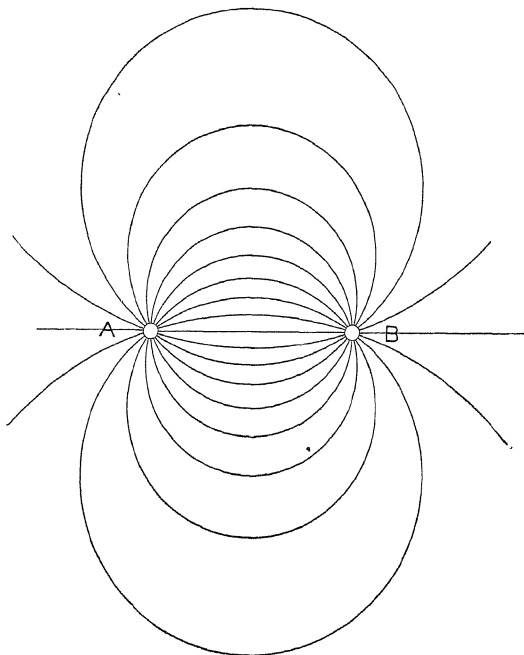
In order to understand the work done by underground water in its journey, it is first necessary to know the path which it follows. Upon this point the recent analytical work of Prof. C. S. Slichter* gives the desired information. He has ascertained that the spaces in soils and in mechanical sediments, so far as the flowage of underground water is concerned, may be considered as a series of triangular tubes. By Prof. Slichter's analysis the flowage of water from one place to another, say from A to B (see Fig. 1), is not by a direct path, but by a large number of diverging paths from A during the first part of the journey, and by a large number of converging paths to B during the latter part of the journey. This may be illustrated by supposing the water to be poured into a well, A, and to flow to a well, B. The horizontal course of the water is represented by Fig. 1, and the vertical course by Fig. 2. These conclusions apply equally well to any porous rock other than a soil or sandstone in which the spaces are distributed in a somewhat uniform manner.

It is apparent that these conclusions have far-reaching consequences as to the flowage of underground water. In the

* "Theoretical Investigation of the Motion of Ground Waters," by C. S. Slichter, *19th Ann Rept U S Geol Surv*, for 1897-98, p. 312.

passage of the water from the top or slope of a hill to a point of issue at the foot of the hill, supposing these to be the only points of entrance or issuance of the water, and

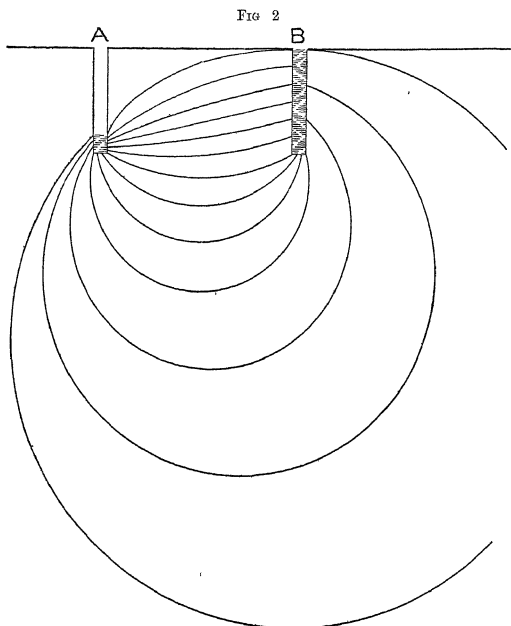
FIG 1



Ideal Horizontal Section of the Flow of Underground Water through a Homogeneous Medium, from One Well to Another

supposing the spaces to be uniform, the vertical course would be represented by the lines of Fig. 3, and the horizontal course would be represented by the lines of Fig. 1. We see at once that for the larger topographic features the vertical component of flow may pass quite to the lower limit of the zone of frac-

ture. This would probably be true even if water throughout its underground journey remained at a constant temperature. But it is to be remembered that the deeper water penetrates, the higher its temperature; also that the movement of water in the

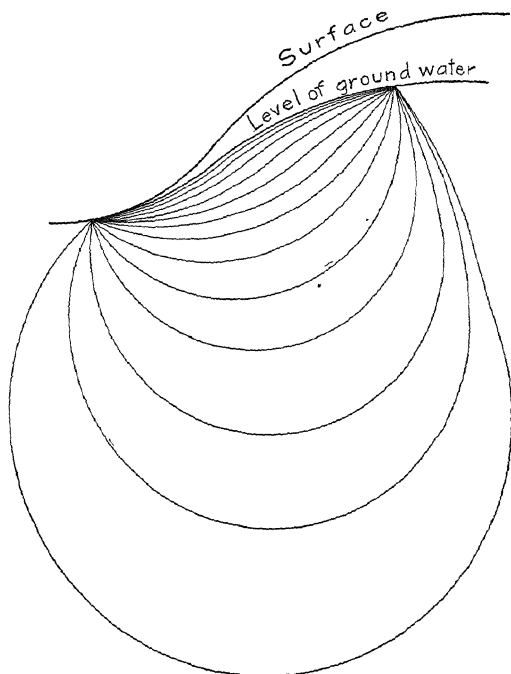


Ideal Vertical Section of the Flow of Underground Water through a Homogeneous Medium, from One Well to Another.

lower part of the zone of fracture is largely through capillary openings; further, that the flowage in capillary openings is inversely as the viscosity; and, finally, that the viscosity decreases rapidly with increase of temperature. Therefore, the increase of temperature with depth is a potent factor favorable to a deep course for underground water. It therefore seems probable

that as a result of head due to topographic irregularities and temperature differences, the entire zone of fracture is being regularly traversed by underground waters. Of course, the

FIG 3



Ideal Vertical Section of the Flow, through a Homogeneous Medium, of Underground Water Entering at One Point on a Slope and Issuing at a Lower Point.

amount of flowage is far greater in the upper part of the zone than in the lower part, but even in the lower half or third of the zone of fracture the amount of flowage cannot be considered small.

The principle of the distribution of the flowage of water over the entire available area is well illustrated by the case of water flowing horizontally into a beaker from one side and overflowing the beaker on the other side. The movement of the water will not be confined to the liquid near the surface of the beaker, but all portions of the water in the beaker from the top to the very bottom will take part in the flowage, although, of course, the rate of movement will be much more rapid at the top than at the bottom.* The well-known hydrodynamical principle thus illustrated, that the entire available cross-section will always be utilized by flowing currents, is directly applicable to lateral moving waters in the zone of fracture. It is conclusive evidence that this zone will be searched to its base by moving waters, although the waters joining and departing from the underground sea appear and disappear at the surface.

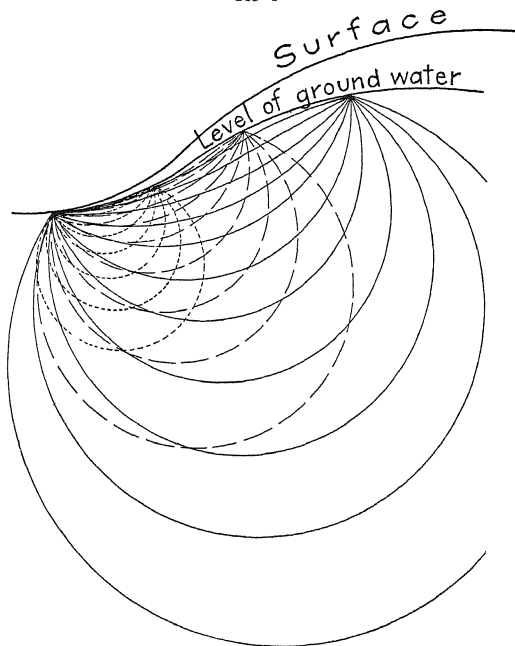
In an actual case of underground flowage the water does not enter the ground at a single point, but enters at every point of a slope. As a sample case, we may suppose that the water entering on a slope reaches the surface again at the level of a stream in an adjacent valley. To get an idea of the complexity of the flow in this ideal case, we may arbitrarily select a number of points where the water enters, and trace out its course. We may plot by different kinds of lines, continuous and broken, the vertical components of the flowage of the water which enters at each place independently of the water that enters at other places. (Fig. 4.) We have a series of intersecting lines in the figure representing the vertical components of movement.

It is not supposed that water actually follows paths similar to those represented by the figure, for there is mutual interference of the water entering at the various points. As a result of this, the water entering the opening nearest the exit would take a more direct course than the average of that plotted, but, as a consequence of this, the water from the next openings up the slope would take a more indirect course, on the average, than that plotted, and so on. The total result would be to give

* Shlechter, *cit*, p. 331, sect. 5. Compare Posepny, *cit*, *Trans. Am. Inst. Min. Engineers*, vol. xxiii, 1894, p. 220.

an average course for the water which can be represented by combining the independent curves. (Fig. 5) The effect, so far as the geological action of the underground water is con-

FIG 4



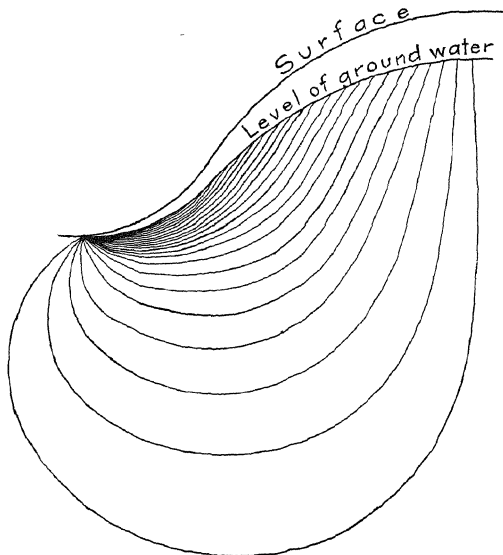
Ideal Vertical Section of the Flow, through a Homogeneous Medium, of Underground Water Entering at Three Points and Issuing at a Single Point, Each System of Flow Being Independent of the Others

cerned, would be approximately the same, whether the course of the water were that represented by Fig. 4 or that represented by Fig. 5. This statement, applicable to a few points of entrance and one of exit, is equally applicable to a great number of points of entrance. The statement can be further ex

tended to an indefinite number of points of entrance distributed along the contours of the slope as well as up the slope, and to many points of exit at or near the level of the valley.

The Preferential Use by Water of Large Channels—In nature the points of entrance for groundwater are indefinitely numer-

FIG. 5.



Ideal Vertical Section of the Flow, through a Homogeneous Medium, of Underground Water Entering at Many Points along a Slope and Issuing at a Single Point of Lower Elevation

ous, and the places of exit comparatively few. The water falls upon the ground everywhere and enters the innumerable pores between the grains. After a longer or shorter underground course, perhaps passing under many subordinate hills and valleys, it escapes to the surface as a spring or by seepage, nearer the drainage-level than where it entered the ground. The

water began its journey through an almost infinite number of openings. It issues at many openings, but these are few compared with the vast number of those at which it entered.

This conclusion is based on the following facts. Openings in rocks are never of uniform size. It has been seen that the resistance to flowage in capillary openings is far greater than in supercapillary openings. In supercapillary openings of moderate size the resistance is greater per unit of flowage than in larger ones. Thus there is a strong tendency for the water starting through innumerable small openings to converge into larger and larger openings, which are the lines of least resistance. Of course, it may go long distances underground, as in some sandstones, without finding larger openings than those near the surface, but if large openings exist, they will be fully utilized. Finally, when a single opening or a group of openings larger than the average reach the surface at a lower altitude than the average level of entrance of the water, there is a spring.

It has been seen that during the first part of the underground journey of water the vertical component is downward, and during the latter part of its journey the vertical component of much of it is upward. It follows that, on the average, the downward movements of water are through the smaller, and the upward movements through the larger, openings in the rocks. Of course, where large openings are available for the downward-moving water they will be utilized; and doubtless the larger openings are utilized to a great extent by the downward moving waters. However, even if this be the case, the statement would still be true that *upon the average* the larger openings are more extensively used by the upward moving water than by the downward moving water. From the foregoing it appears that the system of circulation of underground water has a very close analogy to that of a tree of a peculiar character.

The points of entrance are the ends of the indefinite number of twigs, these twigs unite into a branch; the branches unite to produce a larger branch; the larger branches unite into a trunk; and at the end of a trunk is a spring. The analogy of an underground drainage system to a tree is even closer than that of a surface system, for in a system of underground water circulation three dimensions are concerned to an

important extent, while in a surface system of drainage the movement of the water is approximately confined to a plane. However, from what has gone before, it is clear that the tree of underground water has a peculiar shape. The twigs and branches have an important downward component, the larger branches of the tree may be considered as approximately horizontal, and the trunk usually has an important upward component. Thus twigs, branches and trunks together ordinarily make a great U. The sides of the U may be rather close together in the case of marked topography, where the water issues near the places of entrance. The sides of the U may be very far apart in the case of gentle topography, where there is great lateral movement of the water. Such a system of underground movement is somewhat similar to that of a surface system of drainage.

The analogy of a tree has been utilized in order to get definitely in mind the general character of the circulation of underground water. However, the analogy must not be pushed too far. A tree commonly has but a single, continuous, solid trunk, although willows and other trees have many trunks. Very frequently, indeed commonly, the trunk-channels of underground water circulation are very complex. While a main water course may exceptionally occupy a single open passage, ordinarily it is composed of a number of interlocking passages. These may be the parallel openings of a complex fault, they may be the smaller numerous openings of a zone of fissility, or they may be the more open spaces of sandstones or conglomerates. In short, a trunk-channel of underground water differs only from other channels in that they are places where there is more circulation.

PHYSICO-CHEMICAL PRINCIPLES CONTROLLING THE WORK OF UNDERGROUND WATERS.

Before considering the actual geological work of underground water in the alteration of the rocks and in the production of ore-deposits, it is necessary to consider briefly the physico-chemical principles which control that work.*

* In my treatise on "Metamorphism" (*Monograph U S Geol Survey*) I consider this subject in detail. In the present paper, only that portion of this part of the Monograph is summarized which is absolutely necessary in order to understand the deposition of ore-deposits.

Chemical Action.

The fundamental principle of chemical dynamics is that chemical action is proportional to the active mass. This is the law of mass action *

Chemical action may take place between gases and gases, between gases and liquids, between gases and solids, between different liquids, between liquids and solids, between different solids. So far as the depositions of ores are concerned, the reactions in connection with underground liquid solutions are by far the more important.

The water of rocks, whether at ordinary temperatures and pressures or at higher temperatures and pressures, may take any of the substances with which it comes in contact into solution, may deposit substances from solution; may combine with substances forming hydrates, as in the case of many of the zeolites or of limonite from hematite, may part with its hydrogen in exchange for bases, and especially the alkalies and alkaline earths, thus at the same time changing the composition of the rock and taking the bases replaced into solution, as in the change of enstatite to talc. There may be reactions as a result of different substances being taken into solution at different times, there may be reactions as a result of different solutions coming together, and thus mingling; there may be reactions between substances in solution and the solid material with which the water is in contact, there may be reactions as a result of changing temperature and pressure. All of these changes are of the nature of chemical action. Therefore, by chemical action of underground water is meant the taking of material into solution, the deposition of material from solution, the interchange between materials in solutions, the interchange between materials in solutions and adjacent solids, and, finally, the interchange of the adjacent solid particles. But this last reaction is probably accomplished through the medium of a separating film of water, in which case the apparently simple reaction is really accomplished by transfers between the solutions and solids.

In all these interchanges the materials therefore pass through a state of aqueous solution, and, according to modern ideas of physical chemistry, the salts in aqueous solution are at least

* "Outlines of General Chemistry," by W. Ostwald. Translation by Walker, 1895, p. 292

partly separated into their ions. Their properties in this condition are therefore the sum of the properties of their separated ions. Indeed, the potency of water as an agent through which metamorphism may take place is due, according to these ideas, to its capacity to separate substances which it holds in solution into their free ions. In this power of ionization water exceeds all other solvents. And it is by the migration of these free ions that the interchanges are accomplished. As the greater portion of underground liquid solutions are rather dilute, at least where somewhat free circulation is the rule, we may suppose that the salts held in solution are largely separated into their ions, and therefore these free ions are ever ready for chemical reactions.

Also water reacts upon the salts it holds in solution by hydrolytic dissociation, producing free acids and hydrates of the bases. This process is especially important with the salts of the weak acids.* The dominant acids of nature are the very weak acids silicic and carbonic, and, therefore, hydrolytic dissociation is very important. The silicates of the alkalis in dilute solutions are practically completely decomposed, the result being the liberation of free silicic acid and hydrates of the alkalies, as shown by Kahlenberg and Lincoln.† The carbonates of the alkalis are also, to a considerable extent, similarly dissociated.

Underground Aqueous Solutions.—The quantity of a solid which can be dissolved in liquid depends upon the number and nature of the compounds present, upon the pressure, and upon the temperature.

When a solid salt is placed in liquid, it forms a homogeneous mixture of salt and liquid. This statement applies to all natural compounds,—that is, the minerals of nature are salts which are soluble in water. No substance is wholly insoluble in the underground waters, even at ordinary temperatures and pressures. This statement applies alike to quartz and the most refractory silicates. Under surface conditions, the etching of quartz grains is evidence of the first statement,‡ and the uni-

* "Theoretical Chemistry," by W. Nernst, 1895, p. 660.

† "Solutions of Silicates of the Alkalies," by Louis Kahlenberg and A. T. Lincoln, *Journ. Phys. Chem.*, vol. 11, 1898, p. 89.

‡ "Solution of Silica Under Atmospheric Conditions," by C. W. Hayes, *Bull. Geol. Soc. Am.*, vol. viii, 1897, pp. 213-220.

versal decomposition and partial solution of the silicates is evidence of the second, and in the lower zone of water circulation the solution of quartz and the refractory silicates may be completely accomplished, as in the case of the Calumet and Hecla conglomerates, many of the bowlders of which have been completely dissolved and their spaces taken by copper

The quantity of material which may be dissolved in any case under definite conditions has a limit. When this limit is reached the solution is saturated. This limit depends upon pressure and upon temperature.

The Relations of Solution and Temperature.—The relations of temperature and solution have two phases; (1) the speed of the reaction, and (2) the quantity of material which may be held in solution.

(1) The speed of solution is greatly increased by rise of temperature.^{*} A slight increase in temperature may increase the rate of solution out of all proportion to the absolute change in temperature. At temperatures above 100° C., and especially above 185° C., the activity of water may increase to an amazing degree. The rapid solution of glass by Barus† at temperatures above 185° C. illustrates this. At any temperature solution will continue until the point of saturation is reached. However, it is clear that this state will be attained at high temperatures in but a small fraction of the time required at low temperatures. For instance, to saturate an underground solution with the refractory silicates or sulphides at ordinary temperatures might require months or even years, while to saturate them at temperatures above 185° C might require only an equal number of minutes, or at most hours. The capacity of water for action at high temperatures combined with pressure, considered below, is adequate to explain the complete recrystallization of great volumes of natural glass and crystallized rocks.

(2) The effect of temperature upon quantity of material which may be held in solution does not admit of a simple gen-

* "Theoretical Chemistry," by W. Nernst. Translated by C. S. Palmer, London, 1895, p. 568.

† "Hot Water and Soft Glass in their Thermo-dynamic Relations," by C. Barus. *Am. Journ. Sci.*, 4th series, vol. 1x, 1900, pp. 167-168.

eral statement.* For most substances moderate increase of temperature gives greater capacity for solutions; but for many substances there exists a temperature at which there is the maximum capacity for solution, and the amount of material which may be held in solution at higher and lower temperatures is less than this maximum. For various substances this maximum capacity for solution lies between 60°C . and 140°C ., and for many substances it is probably below 200°C . It therefore follows in underground solutions that a general statement cannot be made as to how change of temperature may affect solubility. However, it is highly probable that up to temperatures of 100°C ., and, therefore, to depths of 3000 meters, increase of temperature increases the average capacity of underground water to hold material in solution. It may be probable that the average capacity of underground water may increase to temperatures considerably above 100°C ., and, therefore, to depths greater than 3000 meters. But when water passes downward to the deeper parts of the zone of fracture the increase in temperature may lessen the average capacity for holding material in solution, provided the joint effect of pressure be barred.

The Relations of Solution and Pressure —In general, the volume of the solvent plus that of the salt is greater than that of the solution. For a given quantity of the solution the contraction is greater the more of the solvent is used †. In some cases, however, the volume of the salt and solvent is less than that of the solution, or expansion results from dissolving the solid. Sal ammoniac in water is an illustration of this case. From the foregoing relations we obtain a rule as to the relations of pressure to solubility.‡ In the common case in which the volume of the solution is less than that of solvent and salt, pressure increases solubility, for in that case solution tends to bring the molecules nearer together and works in conjunction with the pressure. In the reverse case, that in which the volume of the solution is greater than that of solvent and salt, pressure decreases the solubility, the reason being the reverse of that of the previous case.

* "Solutions," by W Ostwald Translated by M M P Muir, London, 1891, pp 55-77

† "Solutions," *cit*, p 82

‡ "Theoretical Chemistry," by W Nernst, 1895, p 567

It is well known that the solubility of calcium carbonate and some other carbonates is increased by pressure * It is a fair inference from Barus' work that the solubility of the silicates is also increased by pressure Barus† found that when soft glass is dissolved in water at temperatures above 210° C, the volume is 20 to 30 per cent. less than the two separately. This glass was one which contains alkalies, alkaline earth and lead, and, therefore, is somewhat similar in composition to many natural silicates. The solubility of many other salts, besides the carbonates and silicates, occurring underground is increased by pressure While, therefore, pressure may lessen the solubility of some natural salts, in the majority of the complex underground solutions the volume of the solution is less than that of the salts and solvent separately; and, therefore, the total of the salts in solution is generally increased by pressure.

It has been pointed out that in the lower part of the zone of fracture increase in temperature with depth may exceptionally lessen the average amount which may be held in solution, but increasing pressure with increasing depth promotes solubility The quantitative values of these two elements are, however, unknown, and no positive statement can be made as to whether the increasing temperature and pressure combined in passing to the lower part of the zone of fracture increases or decreases the capacity of underground water for solution. However, it is clear that to very considerable depths, that is, to 3000 meters or more, the joint effect of the temperature and pressure factors is to increase the average capacity for solution.

Precipitation—After a number of chemical substances are brought together, and especially when they are united by a solvent, interactions between them may occur which, after a time, appear to cease. When the conditions have become such that there is no increase or decrease in the amount of any one of the chemical compounds, the system is in a condition of chemical equilibrium.‡ The interaction may result in the precipitation of compounds.

* "Gold-quartz Veins of Nevada City and Grass Valley, California," by W Lindgren 17th Ann. Report U S Geol Survey, 1895-96, pt 11, 1896, pp 176-178

† "Hot Water and Soft Glass in their Thermo-dynamic Relations," by C Barus *Am Journ Sci*, 4th series, vol 1x, 1900, p 173

‡ Neinst, *cit*, pp 355-356

Since the separation of material from solution in underground waters is of the utmost importance, it is necessary to consider the conditions under which precipitation takes place. It is clear that the necessary condition for precipitation is supersaturation, for if a solution be sufficiently supersaturated some of the material must be thrown down, or be precipitated.

Supersaturation and consequently precipitation may result in various ways, of which the following are the more important (1) By change in temperature, (2) by change in pressure, (3) by reactions between aqueous solutions, (4) by reactions between liquid solutions and solids, and (5) by reactions between gases and solutions or solids, or both.

1 Precipitation by Change in Temperature.—Change in temperature is the rule for underground circulating waters. The waters which are passing to lower levels are upon the average becoming warmer. Waters which are rising to higher levels are upon the average becoming colder. Also, there are changes of temperature both positive and negative due to varying local conditions.

If the temperature of a saturated solution changes in a direction adverse to solution, it tends to become supersaturated. If crystals of the solid in solution are present, and this is usually the case with underground solutions, considerable supersaturation does not occur; for the excess of salt separates, so that at any given temperature equilibrium is nearly retained by continuous adjustment.

It has already been seen that increase of temperature to 100° C. or more promotes solution, and decrease of temperature from 100° C. or more causes supersaturation, and therefore precipitation. One would, therefore, expect that descending waters which are increasing in temperature are, upon the whole, constantly taking additional material into solution, at least to a depth of 3000 meters, and that waters ascending above this level which are becoming cooler are upon the whole precipitating material. However, this statement needs various qualifications. As a consequence of the action of igneous rocks and dynamic action temperatures higher than the normal for a given depth may be obtained. While these temperatures may be so high as to be unfavorable to the quantity of material held in solution, they are very favorable to rapid solution. Since the

temperature is variable which causes the maximum solution of a given salt, it follows that as water passes down through the middle part or lower parts of the zone of fracture, or as it becomes somewhat highly heated because of the presence of igneous rocks or of heat produced by orogenic movement, that the increase of temperature may induce the precipitation of some compounds, and favor the solution of additional quantities of other compounds. Therefore, because of changing temperature in the middle and lower parts of the zone of fracture, and where igneous rocks are present or earth movements have occurred, there is selective solution and precipitation. However, in the normal case within the belt of which we have most exact information, that is, the upper 3000 meters of the crust of the earth, the upward course of water is likely to be favorable to precipitation. (See pp 84-91)

2 Precipitation by Change in Pressure.—It has been seen that where waters are descending the pressure is constantly becoming greater, and they are capable of taking additional material in solution. Where waters are ascending the pressure is constantly becoming less, and they are, therefore, not capable of holding so much material in solution. Hence, the pressure effect in ascending waters is to promote precipitation. All of these statements apply to the average complex underground solutions. Exceptional cases may exist where the reverse effect occurs.

3. Precipitation by Reactions between Aqueous Solutions — Physical chemistry holds that when solutions containing various salts are mixed, the resultant solution will contain all the salts and ions which can be made by the various combinations of their positive and negative factors. In any given case there is a constant relation between the amount of a salt which can be held in solution and the number of free ions of that salt which balance each other, and upon this fact are based the laws of precipitation from solutions.

The laws of chemical precipitation from aqueous solutions are somewhat complex, and cannot be here fully summarized. So far as present purposes are concerned, the old statement of chemistry will suffice. When solutions of two or more kinds are mingled, if a compound or compounds can form which are

insoluble in the liquids present, this will take place and precipitation will follow *

The most important case of precipitation in nature is that resulting from the mingling of aqueous solutions of solids

Another case of precipitation occurring in nature results from mixing solutions, one of which contains a gas. Perhaps the most important case of this kind is the mixing of a solution containing oxygen with one containing salts of iron protoxide. As a result of this, the salts will be changed from ferrous to ferric, and the iron in latter precipitated either as a sesquioxide or hydrosesquioxide. In the latter case hydration occurs simultaneously with the oxidation

4 Precipitation by Reactions between Liquid Solutions and Solids—A very important underground reaction is that between the solutions and the adjacent solid materials. Ordinarily in this case a portion of the solid material is taken into solution and a portion of the material before held in solution is deposited. This principle may be illustrated by the laboratory experiment in which metallic iron is placed in a solution of a copper salt, for instance copper sulphate. The iron goes into solution as sulphate and metallic copper is precipitated. An excellent case illustrating precipitation from solution in nature, one of the most fundamental importance, is the almost immediate partial substitution of magnesium for the calcium of shells and corals by the sea-waters.

In order that crystals in a solvent shall grow, it is necessary that the solutions shall be saturated or supersaturated at the immediate place of crystal growth. Since, underground, there is always a superabundance of solid material present as compared with the amount of water, we may suppose that at a moderate depth below the surface, and especially in the smaller spaces where movement is slow, the solutions are often saturated. It is a well-known fact that under conditions of saturation, with a superabundance of solid material, the larger crystals grow at the expense of the smaller ones, and that this process goes on more rapidly in proportion as the temperature is high and the pressure is great. This principle is taken advantage of in the

* For a more exact statement of the principles of precipitation see the various treatises on physical chemistry. A simple statement of the laws of precipitation is given by C F Tolman, *Journ of Geol*, vol VII, 1899, pp. 587-591.

chemical laboratory in the production of a coarse precipitate before filtration by boiling or other means, the finer particles of the precipitate being dissolved and the coarser ones being enlarged at their cost

5. Precipitation by Reactions between Gases and Solutions, and Solids —The reactions between gases and liquid solutions and solids involve matter in all its three forms. The laws of their mutual interactions are very complex, and they cannot here be taken up. But for the present purpose it may be said that the result of the mixture of gases, liquid solutions and solids, may result in the precipitation of a substance from solution. The most common active gases present underground are carbon dioxide, hydric sulphide, and oxygen. The action of hydric sulphide upon a solution may throw down a sulphide of a metal; the oxidizing action of oxygen may result in precipitation, as in the case of peroxidation of iron. Furthermore, the action of the gases and liquid solutions may together result in the abstraction of substances from the solid compounds and the precipitation of them, or parts of them, elsewhere. The combined action of gases, liquids and solids is more common in the belt of weathering than elsewhere (See pp. 72-74)

THE GENERAL GEOLOGICAL WORK OF UNDERGROUND WATERS.

It has been seen that the geological work of underground waters is dependent on many factors. Some of these are the limitation in depth by the zone of fracture, the nature of the openings in the rocks, the rapidity of the flowage, the character of the materials through which the waters flow, the character of the substances it may carry in solution, the pressure, and the temperature. Of these many factors, two are ever working together according to very definite laws. These are pressure and temperature. Both increase with depth, and therefore greatly promote the activity of deep underground waters. However, of all of these varying factors, varying temperature is the one which is of incomparably the greatest importance. High temperature ordinarily results from depth of penetration, but it has been pointed out that it may result from various other causes, of which chemical action, mechanical action and the presence of intrusive igneous rocks are the more important. The capacity which water has for

taking and holding various relatively insoluble compounds in solution increases as the temperature increases, to 100° C. or more. The velocity of chemical reactions increases enormously with increase of temperature. Not only is high temperature favorable to geological work because of the chemical activity of the water, but high temperature greatly decreases its viscosity, and this, as already explained, is favorable to depth of penetration and flowage through minute openings. Since the temperature changes of underground water are commonly dependent upon depth, the vertical component of the movement of underground water is ordinarily far more important in geological work than the longer horizontal component.

Division of the Zone of Fracture into a Belt of Weathering and a Belt of Cementation.

So far as the work of underground water in the production of ore-deposits is concerned, the zone of fracture may be divided into two belts (1) an upper belt of weathering, and (2) a lower belt of cementation. The belt of weathering extends from the surface to the level of groundwater, and for a variable distance into the sea of underground water. The belt of cementation extends from the bottom of the belt of weathering to the bottom of the zone of fracture.

In the belt of weathering various gases are present, of which carbon dioxide and oxygen are the more important. With these are a great variety of solutions and the greatest possible variety of solids. The reactions in the belt of weathering, therefore, involve gases, liquids and solids. Furthermore, in this belt we have the complicated action of organic bodies upon inorganic bodies. These organic compounds vary in magnitude from the smallest bacteria to large trees, which act both while alive and dead. It is, therefore, clear that the chemical reactions in the belt of weathering are of an extraordinarily complex character. Only the more important of them will be considered. The dominant ones are carbonation, hydration, oxidation and solution.

The process of carbonation takes place upon a most extensive scale in the belt of weathering, producing abundantly carbonates of the alkalies, alkaline earths and iron, and less abundantly carbonates of other metals. Where vegetation is absent

the air in the soil contains only a small amount of carbon dioxide, but where vegetation is abundant and is decaying upon a large scale, the carbon dioxide in the soil is from 15 to 100 times more abundant than in air; hence, in the process of carbonation the presence of vegetation is of fundamental importance. The dominant compounds upon which the process of carbonation acts are the silicates. In the carbonation of the silicates the silica separates as silicic acid *. Since the quantity of silicates decomposed by carbonation is very great, the amount of silicic acid liberated is enormous. This passes into solution, and, as explained below, is transferred to the belt of cementation.

Next in importance to carbonation is hydration. While hydration is usual in the belt of weathering, under some conditions, and especially those of great aridity and high temperature, dehydration may occur.

Oxidation is also very general in the belt of weathering, but deoxidation may occur in regions of very luxuriant vegetation, where there is an unusually large amount of reducing material.

If the compounds formed in the belt of weathering all remained *in situ*, the volume of the rocks would be greatly increased by the above changes, but simultaneously with these reactions, solution, the fourth important reaction of the belt of weathering, is taking place upon a great scale. The quantity of material dissolved is more than sufficient to counterbalance the increase in volume due to the chemical changes, and consequently the volume of the rocks continually decreases. In consequence of this preponderance of solution the openings of the belt of weathering tend to increase in size. However, this is not apparent with the unconsolidated materials at the surface, for gravity brings the particles together as fast as material is dissolved, but in the rocks below the soils, which have sufficient strength to support themselves, the openings are widened. The best illustrations of rocks with enlarged openings are the limestones.

In connection with the chemical changes above summarized, mechanical action is continually subdividing the material

* "Solutions of Silicates of the Alkalies," by L. Kahlenberg and A. T. Lincoln. *Journ. Phys. Chem.*, vol. 11, 1898, pp. 88-90.

In general, then, in the belt of weathering, disintegration, decomposition and solution are the rules. The minerals which remain are usually few and simple; the volume of the rocks is diminished, they soften and degenerate, and they are finally destroyed as coherent solids.

In the belt of cementation, hydration, carbonation, oxidation, and deposition occur. Hydration and deposition are the characteristic reactions. Carbonation and oxidation are subordinate. The reactions take place by metasomatic change within many of the original minerals and by deposition of material within the openings. Many of the minerals produced are strongly hydrated. Because of hydration and deposition the volume of the rocks is increased. Cracks and crevices produced by mechanical action, such as those of faults, joints, bedding partings and fissility, and the openings originally present in the rocks, such as pore-spaces in the mechanical sediments and the vacuoles in volcanic rocks, are slowly but certainly filled by the action of the groundwater, and the rocks are thus cemented and indurated. This process may be called construction.

The belts of weathering and cementation, therefore, contrast strongly. In the former solution continually takes place; in the latter, deposition, in the former we have disintegration, decomposition and softening; in the latter we have cementation and induration, in the former the volume of material is lessened, in the latter it is increased; in the former the characteristic chemical reaction is carbonation; in the latter it is hydration. Therefore, the belt of weathering is characterized by disintegration and decomposition, carbonation, hydration and oxidation, by solution and decrease of volume. The belt of cementation is characterized by cementation and induration, by hydration, by deposition, and by increase of volume.

Migration of Material from the Belt of Weathering to the Belt of Cementation.

It is believed that the material dissolved in the belt of weathering is largely deposited in the belt of cementation. Thus may be explained the steady diminution of a given mass of material in the belt of weathering, and the increase in mass of the material in the belt of cementation. Since this migration

of material is one of great importance, it will be necessary to consider it in some detail

As a result of the horizontal component of the movement of underground water, there is a tendency for material to be taken into solution and to be abstracted by the water. The longer the horizontal underground course, the nearer will the water approach to saturation with the compounds with which it is in contact, because of the time factor. If the journey be long, the state of saturation may be attained at an early stage, after which the additions and subtractions of material upon the average neutralize each other. Throughout the journey there are various chemical interactions. There may be solution of material at a certain place and later deposition of it elsewhere; there may be interactions between the solutions and solids, there may be interactions between the mingled solutions from different sources. However, these reactions do not change the end-result—that is, the longer the horizontal journey the richer the solutions become, and material is abstracted until the point of saturation is reached

Since it is clear that, so far as the horizontal movement of underground water is concerned, the effect is to abstract material, and since deposition, with consequent cementation and consolidation rather than solution is a general fact in the belt of saturation, we conclude that this result must be due to the vertical movement of the water. In the downward journey of the water from the surface to the level of groundwater, it is continuously taking material into solution, and therefore steadily contributes an increment of material to the sea of underground water

After the water reaches the level of groundwater, movement does not cease. Disregarding the lateral movement, the sea of underground water at a given place might be considered as a column moving downward as rapidly as the increment of groundwater is added from above. However, superimposed upon this vertical movement is lateral movement which carries it to some point where upward movement is taking place. Therefore the amount which continues downward is an ever-decreasing fraction of the entire amount of precipitation which joins the sea of groundwater. But for this part the pressure and temperature steadily increase, and the capacity of the

water to take material into solution steadily changes. One might conclude that during at least the first part of the downward course of the water solution was occurring. During the upward course of the water, pressure and temperature steadily become less, and one might conclude that for at least the latter part of the upward course deposition was occurring. However, these simple statements do not fully cover the facts, for, as already pointed out, the relations of temperature and pressure are exceedingly complex, and also deposition, cementation and consolidation seem to be general facts for the belt of cementation

It has already been pointed out that the conditions for solution are very favorable in the downward passage of water through the belt of weathering, and that each unit of water which joins the belt of cementation carries with it in solution a certain increment of material. During the long-continued erosion of a region the belt of weathering at any given time represents the residual disintegrated and partly decomposed material then above the level of groundwater. Thus the belt of weathering is steadily progressing downward. The forces of weathering are continually finding new material at the bottom of the belt upon which to work. Therefore, as denudation goes on there is ever a belt of a certain thickness which contributes material to the belt of cementation below. Hence we have an adequate source for an increment continuously added to the belt of cementation. If this increment thus added to the sea of underground water could be deposited throughout its course in the belt of cementation, there would be a sufficient cause for the induration of this belt.

However, according to one of our fundamental premises, the quantity of water which emerges by seepage or through springs to the surface and joins the run-off must be equal to the amount added to the sea of groundwater by percolation. The question must therefore be asked as to the relative amounts of materials carried to the sea of groundwater by percolation and that abstracted from it by the ascending waters. To this question no answer based upon comparative analyses can be given. However, the general deposition and consolidation in the zone of cementation already emphasized seems to be conclusive evidence that the amount of material contained in issuing

water is not so great as that which joins it through percolation

Of the substances deposited in the belt of cementation, quartz is undoubtedly the one which dominates over all others. The one great process in the belt of cementation is silication. Next in abundance to the quartz, the various silicates are deposited, and especially the zeolites and chlorites. Of less importance are the carbonates of the alkaline earths. Still less abundant are the various metalliferous ores and associated gangue minerals not of the classes already mentioned. While these subordinate products are of great economic importance, their quantity is insignificant as compared with the non-metalliferous deposits.

If it is certain that the one great process of the belt of cementation is silication, it is equally certain that the one great process in the belt of weathering is the carbonation of the silicates, thus forming carbonates and liberating soluble silicic acid. Hence it is highly probable that silicic acid is the dominant constituent contained in solution in downward percolating waters. Therefore we have a source both for the deposited quartz and for the process of silication which forms the silicates. In another place* I have shown that one of the deep-seated dominating reactions is the process of silication of the carbonates or the substitution of silica for carbon-dioxide with the simultaneous liberation of carbon-dioxide. This process takes place at moderate depth, especially under dynamic conditions, although it is especially important in the zone of rock-flowage. The carbon-dioxide liberated in part joins the underground waters. Such carbonated waters are very capable of taking into solution the salts of the metals, and particularly the salts of the alkalis, alkaline earths and iron. The solutions which reach the surface bear as their more abundant compounds the carbonates of the alkalis, alkaline earths and iron. With these are also other salts, including the salts of the valuable metals. Also issuing waters contain other acids besides carbonic acid, such as chlorhydric, sulphydric, sulphuric and others.

From the foregoing it appears that during the circulation of

* "Metamorphism of Rocks and Rock Flowage," by C. R. Van Hise, *Bull. G. S. A.*, vol. ix., 1898, p. 282

water in the belt of cementation the processes of precipitation and solution are selective. Quartz and silicates are the dominant precipitates. Carbonates of the alkalies and alkaline earths are the dominant salts which join the run-off. The above precipitations and solutions are precisely what should be anticipated from the laws of chemical action already given. The compounds which upon the average are thrown down to the greatest extent, are those which are least soluble and most abundant. The compounds which are retained in solution to the greatest extent are those which are most soluble and least abundant. However, of the more soluble and less abundant compounds a portion is precipitated. The conditions under which we would expect partial precipitation of these compounds, at least for the upper 3000 meters, are those of lessening temperature and pressure. These are the conditions of the ascending columns of water. It has already been seen that the ascending columns are likely to be the main water channels. Hence is explained the frequent precipitation of soluble carbonates of the alkaline earths and rare metalliferous ores in these trunk channels.

It is not supposed that the above furnishes a full explanation of the cementation of the entire zone of fracture. It has been pointed out, p 74, that hydration is perhaps the most characteristic reaction of this belt and that hydration results in expansion of volume. So far as this reaction takes place, and it undoubtedly occurs on a most extensive scale, this would tend to fill the openings and thus cement and consolidate the rocks without reference to material from the belt of weathering. Thus, for instance, metasomatic change including hydration in a vesicular basic igneous rock may so increase the volume of the material as to completely fill the vesicles by zeolites, quartz, and other minerals without the addition of any material from an extraneous source. Which of the two factors, material from the belt of weathering, or expansion by the processes of metasomatism including hydration, is the more important in filling openings in the belt of cementation, I am wholly unable to state.

Other factors also, doubtless, enter into the cementation of openings. Some of these have already been mentioned. These are selective solution and precipitation, depending upon varying temperature and pressure, and the reaction of the different solutions upon one another. Another factor which is probably

important is diffusion, but its action is too complex to be taken up in this general paper.

By the various processes of cementation the larger openings are filled with deposits. However, where one of these contains metalliferous ores in sufficient quantity to be of service to man, many thousands are filled with quartz, calcite, dolomite, and other gangue minerals. I repeat again that the deposition of the ores is but a special phase of a general geological process of great consequence

PART II.—APPLICATION OF PRINCIPLES TO ORE-DEPOSITS.

The general discussion in Part I. is believed to contain in large measure the philosophy of the formation of ore-deposits by underground waters. It is now clearer than when first stated that the deposition of the greatest group of metalliferous ores is a special case of the work of underground water

There have been endless discussions as to whether ore-deposits are produced by descending, lateral-secreting, or ascending waters. It is a corollary from Part I that the first concentration of many ore-deposits is the result of descending, lateral-moving, and ascending waters. I say first concentration; for it will subsequently appear that many, if not the majority, of the workable ore-deposits have undergone a second concentration.

The larger, more nearly complete idea of the genesis of ore-deposits comprises all of the old ideas, shows that instead of being contradictory, as supposed by many, they are mutually supporting; combined, they furnish a much more satisfactory theory than any one of them alone. How true these statements are will later more clearly appear.

In the first stage of the concentration of many deposits the waters are descending. During the descent they are widely dispersed in small passages, have an exceedingly large surface of contact with the rocks, come under conditions of increasing temperature and increasing pressure, and are moving slowly downward. All of these conditions favor solution to the point of saturation. The various metalliferous elements present in exceedingly small quantities in the rocks, as well as many other

compounds, are picked up. (See pp. 64-67.) This follows from the law of physical chemistry, that a solution will hold some part of all of the elements with which it is in contact. While deposition as a whole may be occurring in the belt of cementation, solution of the ores certainly takes place.

The waters which perform the first work in the genesis of ore-deposits are descending waters

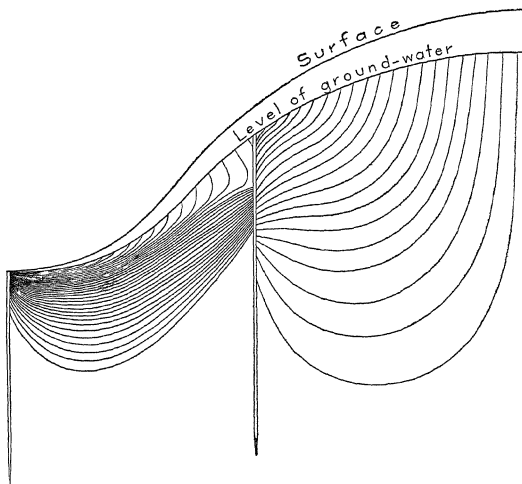
Superimposed upon the downward component of the moving waters is a lateral component. This lateral component, combined with the vertical component, carries water sooner or later to the trunk channels. The amount of water taking part in the lateral movement is greatest near the surface of groundwater, and from that surface steadily decreases to the bottom of the zone of fracture. It has been explained that all fissures and other openings gradually die out below as the zone of rock-flowage is neared. (See pp. 33-36.) Therefore, for a given fissure, the waters which enter it do so from the side or top, not from the bottom. Furthermore, the water does not enter the fissure at a single place, but may enter at numberless points all the way along its course, from the deepest parts of the fissure to the surface. Somewhere, however, the water which enters a fissure must flow from it. This place may be at the surface of the ground or at a considerable depth below the level of groundwater (see Fig. 6). The streams entering the fissure at high levels may have a downward component, and contribute water abundantly. Below the level at which water escapes laterally from a channel of given size, the water contributed to it decreases on the average with increase of depth, until in the deeper part of the zone of fracture the contributions are very small. Posepny* calls attention to the generally observed fact of the decreasing amount of laterally contributed waters as depth increases. As a specific instance of this, he mentioned the Příbram district, in which the water which enters the fissures below a depth of 300 meters is so small as to be insignificant.

While the amount of water laterally entering a fissure steadily decreases from near its top to the bottom, the amount

* "Genesis of Ore Deposits," by F. Posepny (Discussion, 1894), *Trans.*, xxiv, 971

of mineral material per unit volume in all probability steadily increases, for the waters entering at a low level take a longer journey through smaller openings and at higher temperatures and pressures than the waters entering at a high level. Therefore it is clear, if the rocks with which the deeper water comes in contact can furnish metalliferous materials, that such water

FIG. 6



Ideal Vertical Section of the Flow of Water Entering at a Number of Points on a Slope, and Passing to a Valley Below, through a Homogeneous Medium, Interrupted by Two Open Vertical Channels, on the Slope and in the Valley Respectively

will be heavily loaded. It follows from this, even if the amount of water which is furnished in a given brief time to a fissure be small, that such water may furnish from the country-rock much more mineral material in solution than sufficient to entirely fill a fissure during its long life. This is evident from the following. Water issuing at the surface from mineral springs generally contains more than 1 part of silica in

100,000 * If it be premised that only as much silica be deposited as issues at the surface, in order completely to fill a fissure it would be necessary only to suppose that the amount of water which enters a unit length of a fissure is 100,000 times as great as the volume of a unit length of the opening

We now understand that the amount of water entering a fissure decreases from the level of groundwater to its bottom, but that the amount of mineral matter brought into the fissure by the water (but not necessarily deposited) increases per unit volume from top to bottom. It is, therefore, impossible to make a general statement as to whether more mineral material is contributed to a trunk channel in its upper portion or in its lower portion. Doubtless this varies in different cases. Other conditions than amount of water or depth may be controlling factors in this respect. For instance, if igneous rocks be intruded at high or low levels only, the presence of the igneous rocks may furnish conditions which determine the amount of metalliferous material contributed by the waters

While the foregoing paragraphs imply that the lateral moving waters are also downward moving, this is meant only as a general rule. The lateral movement may be accompanied by no downward movement. Not only this, but lateral movement may be accompanied by an upward component. Indeed, this is believed to be very frequently the case, especially so far as the main branch streams in the deeper parts of the zone of fracture are concerned. In so far as there is an upward component in these branch streams, the reactions which obtain are the same as those of the trunk channels to be considered below.

From the foregoing, it appears that ores are carried to trunk channels by laterally moving waters. Lateral secretion is therefore an essential step in the first concentration of ore-deposits, although I use the term lateral secretion in a broader sense than did Sandberger.

We have now reached the place where the ore-deposits themselves are found. As already noted, these mainly occur in the more continuous larger openings. These openings are

* "Lists and Analyses of the Mineral Springs of the United States," by A. C. Peale, *Bull. U. S. Geol. Surv.*, No. 32, 1886

occupied by the trunk streams of circulating waters, and therefore the journey of the water is in the latter part of its course. Hence these trunk streams, as has already been shown (p 61), have in general an upward rather than a downward vertical component. The waters reaching the trunk channel at any point immediately begin their ascent. At any given cross-section of a channel there must pass all of the water contributed below. This amount at great depth has already been seen to be small. From a small amount, the waters steadily increase in volume to the point where they begin to escape laterally from a trunk channel (see Fig 6). Hence from a trunk channel of a definite size the circulation is slow below and increases in speed above. Near the bases of the channels from which the Mammoth Hot Springs and geysers of the Yellowstone Park issue the amount of water contributed may be small, and the movement of the water may be exceedingly slow. Even if true, as held by some, that rapid movement of water is unfavorable to deposition of ores, it is wholly possible at moderate depths and especially in the deeper parts of a channel from which the flow at the surface is rapid, that the conditions are those of slow movement and rapid precipitation of ore-deposits.

As the water passes upward, the variety of solutions as well as the amount increases; for each stream differs in its salts from any other, since no two streams can possibly have had exactly similar histories. Moreover, the character of the wall-rock may vary from place to place. The pressure and the temperature are also lessening. These conditions are favorable to precipitation. *Therefore, many ores in their first concentration are precipitated by ascending waters.*

It is now clear that a satisfactory account of the genesis of ores includes ascending waters. By the ascending waters many ores in their first concentration are actually precipitated, and thus the emphasis which has been placed upon this part of the work of circulating waters.

The broader statement of the genesis of a great class of ore-deposits is that the water after penetrating the earth is widely scattered in contact with rocks in innumerable minor openings. These waters travel downward with steadily increasing pressure and temperature. They take up the constituents of the ore-

deposits. The downward movement of the waters has superimposed upon it a lateral component, as a result of which the waters are carried to the larger openings. During this process, also, the waters continue to take material into solution. In the larger openings where the waters are congregated they are upon the average at first ascending with decreasing temperature and pressure, and there the ores are precipitated.

Of course, from this statement it is not meant to imply that materials are not deposited by descending and lateral moving waters, nor that materials are not dissolved by ascending waters. Indeed, it is certain that solution and precipitation are taking place at all times throughout the entire course of all the branches of the underground circulation. This is a necessary consequence of the laws of physical chemistry. It is only meant to imply that in the first concentration of one class of ore-deposits, solution so far as the ores are concerned is the rule for the descent and deposition for the ascent, although there is no doubt that there are many local exceptions to this.

It is of course understood that the underground circulation in any actual instance will be much more complex than that given in the simple ideal case which has been considered. This part of the subject will be developed. For instance, it is certain that, in the same mineral-bearing area, immediately adjacent trunk-channels may have had very different histories. This is especially well shown by the deposits of Butte, Montana, where there are two parallel main zones of mineralization, only a short distance apart, the mineral wealth of one of which is mainly copper, while that of the other is mainly silver*. Many of the other special factors which modify the simple general statement above given are discussed on pp. 138-166.

THE PRECIPITATION OF ORES BY ASCENDING WATERS.

The precipitation of ores in the trunk-channels by ascending waters is of so much importance in the concentration of ores that this process needs further consideration. The precipitation results from the various principles given pp. 67-71

* "Notes on the Geology of Butte, Montana," by S. F. Emmons *Trans.*, **xvi.**, 54, 1888.

Precipitation by Decrease of Temperature and Pressure

The general relations of solution and precipitation as a consequence of varying temperature and pressure have been considered pp 68-70. Where the increment of temperature is normal, it has been seen that decreasing temperature and pressure resulting from the ascension of waters from at least a depth of 3000 meters are favorable to precipitation. Furthermore, the same statement holds even if the increment of temperature is greater than normal, provided the temperature does not greatly exceed 100° C., and cases in which water issues at the surface at such temperatures are very rare. Moreover, probably decreasing pressure and temperature with rising solutions at depths greater than 3000 meters are favorable to precipitation. Since it has just been shown that ascending waters are likely to be in trunk-channels, these are the places where lessening temperature and pressure are most likely to produce precipitates. Therefore the openings of faults, joints and bedding partings and the more open places in porous sandstones, conglomerates and amygdaloids, are likely to have material precipitated in them as a consequence of lessening temperature and pressure.

When one attempts to apply these general statements to specific salts, we find experimental data lacking. It is undoubtedly the case that decreasing temperature and pressure are much more influential in the precipitation of some salts than of others, and that with a few salts decreasing temperature and pressure are favorable to solution. Until experimental work has determined how the various salts commonly found underground respond to changing temperature and pressure, it is impracticable to specify the ores the precipitation of which are strongly favored by decrease of temperature and pressure. One would expect that precipitation as a consequence of changing temperature and pressure would tend to give a somewhat orderly vertical distribution of the various metalliferous ores.

Precipitation by Mingling of Solutions.

Precipitation in the trunk-channels is produced by reactions caused by the mingling of various solutions. The solutions may be those of solids in the water, or of gases in the water, or of both. According to the modern theory of solutions, a solid

dissolved in water is in the form of a gas, and therefore, so far as the precipitation is concerned, it makes no difference whether the substance in the water, if separated, would be a solid or a gas.

It is evident that solutions from different sources are entering a given trunk-channel at many places. Each of the incoming streams will have a solution different from that entering by any other stream, although in many cases the differences may be slight. As a case of certain considerable differences may be mentioned the ascending and descending streams. (See pp 122-123) Thus a multitude of streams of different composition enter and mingle in a trunk-channel. If in a chemical laboratory a multitude of solutions taken at random are thrown together, it is certain that various precipitates will be formed. It is just as certain when the various solutions in an underground channel come together that precipitates will frequently form. This mingling of solutions is one of the most important of all the factors which results in the deposition of the ores. I have little question that in this fact of the wide variety of solutions which enters a given channel we have in a large measure the explanation of the variable richness in ore-deposits in a given fissure. It is well known that an ore-deposit varies in richness in an exceedingly irregular manner. At a place in a fissure where a metal is abundantly found, the explanation in many cases is certainly that at or near that place there entered a stream which either carried the precipitated metal or carried an agent capable of precipitating the metal which was already in the trunk-channel. For instance, it is believed that where the great bonanza of the Comstock lode was found, there or near there entered either solutions rich in gold and silver which met other solutions capable of precipitating this gold and silver, or else at that place there entered a solution having a compound which was capable of precipitating the gold and silver already traveling upward within the lode. Perhaps the former hypothesis is the more probable.

Ore-chutes, or chimneys of ore of exceptional richness, are very frequent phenomena in veins. These are sometimes parallel with the dip, at other times pitch to the right or left of it. The explanation of these ore-chutes in many instances I believe to be a cross-fracture or joint through which waters entered, either carrying metalliferous material itself or solutions

capable of precipitating the metalliferous mineral in the trunk-channel at the place where the lateral streams of water entered.

The lead and zinc deposits of the Mississippi valley, according to Jenney, are larger at the crossings of two sets of fissures than elsewhere. This may be partly explained by the greater abundance of the solutions furnished by two sets of fissures, but are probably at least partly explained, as suggested by Jenney,* by the mingling of two different kinds of waters, thus giving conditions favorable for precipitation.

In the Enterprise mine, at Rico, Col., described by Rickard,† the ore-bodies are in vertical veins and in flats under shales. While a set of cross-veins is barren, "the rich ore-bodies overlie them in the contact zone." Below the shale it is common to find ores of more than average grade in the pay veins where they are broken by the cross-veins. It is believed the explanation of these relations is the reactions resulting from the mingling of the solutions of the "verticals" with the inclined cross-veins.

The silver-lead deposits of the Aspen district of Colorado, described by Spurr,‡ furnish an instance of very probable precipitation of rich ore-chutes by the mingling of solutions. Spurr states that generally an ore-body is "found at the intersection of two faults, one of these faults usually dipping steeply, while the other is much flatter." For this "the explanation is offered that by the mingling of solutions which had previously flowed along different channels the precipitation of metallic sulphides was brought about."

Probably the rich ore-chutes of gold ore in the Sierra Nevada, which, according to Lindgren, pitch to the left as one looks down the veins, further illustrate the principle of precipitation by mingled solutions. For the most part, Lindgren makes no statement as to the relations of ore-chutes and lateral seams. However, on the Canada Hill vein there are "occasional rich bunches at the intersections" of the two systems of veins.§

* "The Lead and Zinc Deposits of the Mississippi Valley," by W. P. Jenney, *Trans.*, xxii, 1894, pp. 189-190, 224.

† "The Enterprise Mine, Rico, Col.," by T. A. Rickard, *Trans.*, vol. xxvi, 1897, pp. 977-978.

‡ "Geology of the Aspen Mining District, Colorado," by J. E. Spurr, *Mon. U. S. Geol. Survey*, No. 31, 1898, pp. 230, 234-235.

§ "The Gold-quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann. Rept. U. S. Geol. Surv.*, pt. II., 1896, p. 195.

It is believed that the Cripple Creek deposits likewise illustrate this principle. Penrose* notes that many of the rich ore-chutes occur at cross-fissures. The formation of these ore-chutes at such places is doubtless partly explained by the greater amount of solutions furnished at an intersection of two trunk-lines of underground circulation; but it is thought probable that the main cause for the formation of ore-chutes at such places is the reaction of solutions furnished by one set of fissures upon those furnished by the other set. However, it is but far to say that Penrose makes the explanation the "mechanical one, in deflecting the course of the ore-bearing solutions."

While apparent irregularities in the kinds and percentages of metals are doubtless in many cases explained as above, the distribution of the metals in a definite order from the surface downward, and the general law that many valuable metalliferous ores grow poorer in depth if the measure be 1000 meters or more are to be explained by other principles. Of these, varying temperature and pressure are important, but more important in many instances, as will be shown subsequently, is a second concentration produced by descending waters.

Reactions Due to Wall-Rocks.

Precipitation of metalliferous ores from the solutions in the trunk-channels due to the influence of the wall-rocks are frequently produced in the following ways. (1) It has already been explained that a solid when placed in contact with a liquid may precipitate some compound previously held in solution, some part of the solid going into solution at the same time. Thus, the wall-rock may precipitate ores. (2) The wall-rock produces an effect upon the trunk-solutions by furnishing precipitating solutions to it, and this may result in precipitation of metals already in solution within the trunk-channels. (3) The wall-rock itself may furnish metalliferous material for the ore-deposit which may be precipitated when it reaches the trunk-channel by the solutions there contained. This has been greatly emphasized, probably over-emphasized, by Sandberger. Where the wall-rock is easily soluble, ready enlargements of the openings occur,

* "Mining Geology of Cripple Creek, Colorado," by R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Surv., 1894-95, pt. II, pp. 164-165, 1895.

furnishing places for the deposition of the metalliferous material. (See pp 158-161)

It is believed that the effect of the wall-rock in these various ways in the production of many ore-deposits is of great importance. As an illustration, may be cited the very general association of lead-ores with limestone. Probably by far the larger portion of the lead-ores mined in the past have come from within limestone. I believe it to be highly probable that the position of the ores in limestone is due to the character of this rock. Any one of the factors above mentioned might be more important in a given case, but doubtless in many instances two or more work together. Thus, the position of the lead in a limestone may be partly explained by reactions between the solutions of the trunk-channel entering the limestone and the limestone itself. Or, the precipitation of the lead may be partly the result of the reactions between the solutions furnished by the trunk-channel and the solutions furnished by the limestone. In a given case the waters of a trunk-channel entering the limestone may be acid. The solutions from the limestone would immediately react upon this solution, tending to neutralize it, and the precipitation of lead sulphide might be a consequence. Or, the wall-rock might furnish the lead, as in the Mississippi valley. The ready solubility of the limestone would furnish the openings and caves, giving a receptacle for the lead, as in southwestern Wisconsin.

A still clearer case of precipitation resulting from the influence of the wall-rock is the well-known occurrence of metallic copper about grains of magnetite, and in the openings of sandstones, conglomerates and amygdaloid of Keweenaw Point.* Where the copper is about the magnetite it seems perfectly clear that the protoxide of iron in the magnetite was the reducing agent which precipitated the metallic copper.† The metallic copper between the particles was doubtless precipitated by ferrous solutions furnished by the wall-rocks, which in many cases are basic volcanics

The reactions due to the country-rock are more likely to be effective in proportion as it is porous, and therefore allows solu-

* "The Copper-Bearing Rocks of Lake Superior," by R. D. Irving, *Mon U. S. Geol. Surv.*, No. 5, 1883, p. 420.

† Irving, *op. cit.*, Pl. XVI., Fig. 1

tions to permeate it. The country-rock is especially effective in its reactions where the trunk-channel is a complex one, and gives a large surface of action. This is illustrated by the Calumet and Hecla conglomerate, by the Cripple Creek ore-deposits,* and by many other districts (see p. 140).

A particularly clear illustration of the effect of the wall-rock is furnished by ores in which the sulphides are confined to strata containing organic matter, as in some copper-deposits† and some of the gold-reefs of Australia. In the case of the copper-deposits, the organic matter has in all probability reduced sulphites or sulphates to sulphides. The function of the organic material in the case of the gold may have been to reduce it to metallic gold, or to reduce it through the production of *ous* salts, for instance, ferrous sulphate (see pp. 118-120).

General.

In conclusion, it may be said that the precipitation of metallic ores by the mingling of various solutions is probably the most important single factor which results in the first concentration of ores. Probably next in importance to this are the reactions upon the trunk-streams due to the wall-rocks. Inasmuch as the waters of lateral streams from beyond the wall-rocks must pass through the latter, many of the streams contributing through the wall-rocks to the trunk-channels produce an effect partly due to materials more remote than the wall-rocks and partly to the wall-rocks. Thus in many cases the effect of solutions beyond the wall-rocks and that of solutions furnished by the wall-rocks cannot be discriminated. However, since the effect of the wall-rocks has been so much discussed, it seemed to me best to treat the two separately as far as practicable.

Diminishing temperature and diminishing pressure, while probably subordinate in their effect to the mingling of streams and reactions due to the wall-rocks, are in many instances undoubtedly important, and in some instances may be the dominant factors. In general, the tendency of writers has been to

* "Mining Geology of Cripple Creek, Colorado," by R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Surv., 1894-95, pt. II, p. 163, 1895.

† "The Genesis of Ore-Deposits," by F. Posepny, and Discussion of same, by F. M. F. Cazin, *Trans. Am. Inst. Min. Eng.*, vol. XXIII., 1894, pp. 316, 606-607.

emphasize the effect of diminishing temperature and pressure, and to minimize or even disregard altogether the effects of mingling solutions or the wall-rocks, or both.

The Compounds Deposited by Ascending Waters.

Of the metalliferous ores, those of iron, copper, lead, zinc, silver and gold are the more important. Where these are deposited by ascending waters they occur mainly as sulphides. In many cases the sulphides are simple binary salts. However, sulpharsenites and sulpharsenates, sulphantimonites and sulphantimonates are common, but these also are sulphides, and all will be thus referred to without qualification. Besides sulphides, metallic products sometimes occur, as in the case of copper and silver; also tellurides, carbonates and silicates are formed.

Why average compounds deposited by ascending waters are, for the most part, not oxidized compounds, but sulphides, tellurides, or metallic compounds, is easily explained. The widely disseminated, downward-moving water, bearing oxygen, is robbed of this constituent early in its course. Ferrous compounds are abundantly present in the rocks in the forms of magnetite and silicates. Iron is a strong base; and where ferrous compounds are present they continue to abstract the oxygen of the downward moving waters until it has practically disappeared. Moreover, buried organic matter takes oxygen from underground waters. In believing that the sulphides are commonly precipitated by ascending waters in the openings below the level at which oxidizing solutions are active, I follow Le Conte and Posepny.*

Source of the Metals.—The nature of the rocks which contribute the metallic salts has been much discussed. With Sandberger,† I have little doubt that the metallic constituents of ores are in large part derived from the igneous rocks which have been intruded or extruded into the lithosphere; and especially is this true of the basic rocks. Le Conte‡ points out that the undoubted frequent occurrence of workable ore-deposits in regions of vulcanism may be explained by the heat furnished by the

* "On the Genesis of Metalliferous Veins," by Joseph Le Conte *Am Journ Sci*, third series, vol xxvi, 1883, p 4 "The Genesis of Ore-Deposits," by F Posepny, *Trans.*, xxiii, 1894, p 236

† "Untersuchungen über Erzgänge," by F Sandberger, 1882.

‡ *Op. cit*, p 10.

igneous rocks, this promoting the work of underground solutions. That the heat furnished by the igneous rocks is a very important factor in the production of the ore-deposits, I have no doubt. Since it is very difficult to prove that the metallic content of an igneous rock is original, it is impossible to make any general statement as to whether the metallic content or the heat furnished by the igneous rocks is the more important in the production of ore-deposits. It seems to me clear that both are important; and equally clear, in many cases, that both work together. That is to say, an igneous rock may furnish all or a part of the metal which appears in an ore-deposit, and the heat of the same igneous rock may greatly assist its concentration by the underground waters.

While the massive igneous rocks are the undoubted source of a large portion of metallic deposits, it is also equally certain that another large part is derived from the sedimentary rocks and the metamorphosed, or partly metamorphosed, igneous and sedimentary rocks. Lastly, it is also certain that many ore-deposits derive their metalliferous content in part from igneous rocks and in part from sedimentary rocks. Probably this is the most frequent of all cases. To give any estimate of the relative amounts of metalliferous materials derived from the original igneous rocks and from the secondary rocks is quite impossible.

This statement will, of course, be very unsatisfactory when applied to an individual district. However, it is not the purpose of this general paper to consider individual districts, except as they illustrate principles. It is properly the part of the geologist or mining engineer who studies an individual district to find the source of the metal. In many cases, careful investigations can undoubtedly determine this point, as, for instance, that of the iron-ores of the Lake Superior region. In other districts, however, the most exhaustive study may not enable the investigator to determine the source of the metalliferous material. This is especially likely to be true of ore-deposits produced by ascending waters from a somewhat deep circulation. The underground waters may have their sources of supply in rocks which do not reach the surface, and have not been penetrated by the mine workings.

In concluding this part of the subject, it may be suggested that in many instances mistakes have been made in assuming

that some one formation, sedimentary or igneous, is the sole source of the valuable metals. Such an assumption is particularly prevalent in papers descriptive of gold deposits and silver deposits. In many districts where there are various sedimentary and igneous rocks, I have no doubt that the silver and gold are partly derived from two or several formations.

Source of the Sulphur of Sulphides—According to modern research, the metallic sulphides are original constituents of igneous rocks. This is a direct observation; but even if the observation had not been made, the large amount of sulphur compounds issuing from the interior of the earth in connection with vulcanism would lead to the conclusion that sulphides must exist in the igneous rocks. It is therefore probable that sulphur, as sulphide, is or was present in sufficient quantity in the original rocks to fully account for all of the sulphur compounds in the ore-deposits.

It is, of course, well known that sulphides in the belt of weathering are largely oxidized to sulphites and to sulphates, and taken into solution by descending waters. These compounds join the sea of underground water. There the sulphites and sulphates, either just below the level of groundwater or at a greater depth, may come in contact with buried organic material. Under these conditions it is well known that the sulphites and sulphates are reduced to *ous* salts, or to sulphides.

Occasionally the metals may be carried to the trunk-channels as sulphites and sulphates, and there be reduced to sulphides. This would be especially likely to happen where the ores are disseminated through beds bearing carbonaceous material. Cazin mentions the Vermont copper-mine as a case where the ores are mingled with organic material.* Rickard mentions a number of cases where the deposition of the ores is confined to material containing organic matter, the more important being those gold-bearing sulphide reefs of Australasia, California and Colorado, where the ore is associated with strata bearing organic matter †

* "Discussion of the Genesis of Ore-Deposits," by F. M. F. Cazin, *Trans.*, xxiii, 1894, 606-607

† "The Origin of the Gold-Bearing Quartz of Bendigo Reefs," T. A. Rickard, *Trans.*, xxii, 1893, 314-315. "The Enterprise Mine, Rico, Colo.," T. A. Rickard, *Trans.*, xxvi., 1897, 977-979

In one case of the gold-quartz veins of California, in carbonaceous argillite, pyrite occurs in the argillite but not in the quartz. This is very strongly suggestive that the carbonaceous matter of the argillite has reduced the sulphates to sulphides. This occurrence in the California gold-belt is especially suggestive, since the analyses of two springs of ascending waters at the 400-foot levels in two separate mines show the presence of considerable quantities of sulphates.*

Probably also sulphites and sulphates may be reduced to sulphide by ferrous iron in the rocks. If this reaction takes place, it should be especially characteristic of the more basic rocks. The frequent occurrence of sulphides in the altered basic rocks, and especially the scoraceous basic rocks, is very strongly suggestive that this reduction has taken place. So far as I know, this reaction has not been before suggested. It is probably an important one in the reduction of the sulphites and sulphates to sulphides in the lower part of the zone of fracture, and may explain the deposition of sulphides in rocks where organic material is not available for the reduction.

The sulphides, whether as original constituents of the igneous rocks or produced by the above reactions, are taken into solution and deposited in the main channels of water-circulation. Of the fact of the solution and deposition of the sulphides there can be no doubt. However, the solvents in different cases are doubtless different, and moreover, in a single case, the solvents are probably complex. It is well known that the sulphides of the valuable metals are somewhat freely soluble in alkaline solutions, and especially solutions of the alkaline sulphides †. Furthermore, from observation in the field it is known that certain of the sulphides have been thus transported, as for instance at Steamboat Springs and Sulphur Bank, ‡ and doubtless this manner of transportation is very common. However, as shown in another place, the bicarbonates with an excess of carbon-dioxide are the most abundant compounds in underground solutions. These bicarbonates are largely those

* "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann Rept U S Geol Surv*, pt ii, 1895-96, p 81; also Plate VIII, p 140, and pp. 121-123, 172-173

† Lindgren, *op cit*, pp. 177-178

‡ Le Conte, *cit*, *Am Jour Sci*, Third Series, vol xxvi, p 3

of the alkalis and alkaline earths. Such carbonated waters also favor the solution of sulphides. Furthermore, sulphides are doubtless rendered more soluble by the presence of various other compounds in the underground solutions. However, the transportation of sulphides is not limited to solutions which bear other compounds; for the sulphides themselves are soluble in pure water to some extent, as has been shown by Doelter.*

But in whatever form the sulphides are transported, they are largely precipitated in due time in the trunk-channels. By denudation these sulphides may again reach the belt of weathering when the cycle is complete. The sulphide may be again oxidized to sulphate, and so on. It is therefore clear that sulphur, as sulphide and sulphate, may again and again take part in the deposition of ores;† but the first source of the sulphur must be the sulphides of the original rocks.

In this connection Chamberlin has noted that in Wisconsin waters comparatively near the surface bear oxygen and oxidized compounds, while deep artesian waters are "marked by slightly sulphuretted waters."‡ Thus analyses of waters in a region of comparatively undisturbed sedimentary rocks confirm the statements of the previous paragraphs. That is to say, waters which are deep-seated, and therefore must take an upward journey to reach the surface, are likely to bear sulphides.

While it is believed that sulphides are generally deposited by upward-moving waters, this is not supposed to be the universal case. Nature's processes are always too complex to be covered by a single general statement. As a result of mingling solutions at various places, and of reactions between solutions and walls, many lateral moving and downward moving streams doubtless do deposit rather than dissolve sulphides. Indeed, in the frequent case already noted, where in downward-moving waters, sulphites or sulphates are reduced by organic matter to sulphides, precipitation of a portion of the sulphide is usual. But still the statement would hold true that upon the average more sulphides are dissolved by descending waters than deposited, and more sulphides are deposited by ascending waters than dissolved.

* Lindgren, *op cit*, pp 179-180.

† Le Conte, *op cit*, p. 13. Compare Posepny, *Trans*, xxiii, 1894, 263.

‡ "The Ore-Deposits of Southwestern Wisconsin," by T. C. Chamberlin, *Geol. Wis*, vol. iv, 1882, p. 547.

We conclude, therefore, that, *whatever the source of the sulphides as first concentrates, these ores are generally deposited by ascending waters in the trunk-channels.*

Source of the Carbonic Acid of Carbonates.—Aside from sulphhydric acid, the other acid of great importance in the deposition of ore-deposits is carbonic acid. This as is well known is, indeed, the dominant acid contained in issuing underground waters. This point both Le Conte and Posepny strongly emphasize.* I have already pointed out two sources for the excess of carbon-dioxide held in the underground waters. Where vegetation is abundant, carbon-dioxide is concentrated in the soil. A large part of this is retained in the belt of weathering by the process of carbonation of the silicates, but another part joins the sea of underground waters. Another source for the carbon-dioxide is that liberated from cavities within rocks. It is well known that in many rocks a large amount of carbon-dioxide is included in innumerable microscopic cavities. When such rocks are complexly deformed in the zone of fracture, the fractures must intersect many of these cavities, and thus liberate the carbon-dioxide. Where there are zones of crushing, that is, where there are trunk-channels for percolating waters, the amount of carbon-dioxide which may thus be liberated may be considerable. Another source for the carbon-dioxide is a process of silication, explained p. 77, as a result of which the carbonates are decomposed by the silicic acid at depth, liberating the carbon-dioxide. Therefore, deep-seated waters are ever receiving contributions of carbon-dioxide, and thus are continually more capable of taking metals in solution, until the waters reach conditions where silication does not occur.

In this process of silication alone is believed to be an adequate source of carbon-dioxide; so that metals may be carried as bicarbonates and the water also hold a further excess of carbon-dioxide.

A very interesting confirmation of the liberation of silica by the process of carbonation near the surface and the liberation of carbon-dioxide, probably by the process of silication at depth, as above explained, is furnished by the Geyser mine of Custer county, Colorado, described by Emmons.† Here waters were

* Le Conte, *op cit*, p 11 Posepny, *Trans*, xxiii, 237

† "The Mines of Custer County, Colorado," by S. F. Emmons, 17th *Ann Rept U S Geol Surv*, pt. 11, 1895-96, pp 460-464

analyzed from the 154 meter and the 615 meter levels. The superficial waters contained ten times as much silica as the deep-seated waters. In the deep waters the carbonic acid is greatly in excess of that contained in the vadose circulation.

General.

The foregoing statement explains to some extent the source of the compounds deposited by ascending waters. But it is not the intention here to discuss its application to each individual metal. This I do not attempt, because I lack the necessary accurate observations upon which such a discussion should be based. To tell in what manner each of the individual metals is carried will require very detailed investigation. For instance, the questions as to the condition in which gold occurs in the original rocks, the manner in which it is carried in solution, and the form in which it is deposited have been much discussed. However, the difficulties in this and other cases, since the modern theories of physical chemistry have been developed, do not seem to be so great as when it was supposed that we must regard each metal in solution as combined with some one acid. It has already been stated that all substances are soluble in water, and somewhat readily soluble in various underground solutions. It is believed that in the very dilute underground solutions, metallic salts are largely in the form of free ions. Therefore, in one sense, gold and other metals in solution are not combined with acid ions, although they are balanced by them. Where precipitated, a metal might be thrown down in the metallic state, as, for instance, copper, silver or gold, by the ions which once balanced it being balanced by other metals.

While it is not the purpose here to take up the solution and deposition of the compounds which occur in ore-deposits in detail, it is necessary to refer to the law of mass-action in this connection. Other things being equal, those compounds which are abundant will be dissolved in larger degree during the downward course of the waters, and the same compounds will be most abundantly precipitated in the trunk-channels. It is well known that iron is the most abundant of all the metallic compounds in the crust of the earth. In this fact, combined with the law of mass-action, we have the dominating abundance

of iron sulphide as compared with all sulphides of other metals. It is well known in many cases that the deeper a mine goes below the level of groundwater, the greater the proportion of iron sulphide and the less the proportion of the other metals, as a result of which, combined with increased cost of working, it frequently does not pay to work a deposit beyond a certain depth. The law of mass-action explains the abundance of the iron sulphide; it does not explain the frequent relative increase in the iron sulphide and the decrease of more valuable sulphides as one passes from the level of groundwater into deep workings. To explain this we must take into account the effect of the downward-moving waters, discussed under the succeeding heading.

We have now seen that the zone of fracture is searched by the percolating waters; that metalliferous materials taken into solution by the downward and lateral moving waters are carried to the trunk channels of underground circulation, that in these trunk channels the metalliferous materials are precipitated in various ways. Thus a first concentration, by ascending waters giving sulphurets and metals of some of the elements, is fully accounted for.

In some cases the deposits thus produced are sufficiently rich, so that they are of economic importance. In these cases, which undoubtedly exist, but which perhaps are less numerous than one might at first think, a concentration by ascending waters has been sufficient.

A conspicuous illustration of ore-deposits of this class which may be mentioned are the metallic copper deposits of the Lake Superior region. The copper was in all probability reduced and precipitated directly as metallic copper from upward moving cupriferous solutions. The reducing agents were the ferrous compounds in the solid form, in part as magnetite and as solutions derived from the iron-bearing silicates. When the copper was precipitated, the iron was changed into the ferric condition.* It is well known that metallic copper once formed is but slowly affected by the oxidizing action. Oxidation has, in fact, occurred in the Lake Superior region, but from the

* "Paragenesis and Derivation of Copper and its Associates on Lake Superior," by R. Pumpelly, *Am. Jour. Sci.*, Third Series, vol. 11, 1871, p. 353

facts now to be observed not to an important extent. An oxidized belt may have formed in pre-glacial times, but if so it was swept away by glacial erosion, and sufficient time has not since elapsed to form another. The ore-deposits now worked have apparently remained practically unchanged since the time of their first concentration. In this fact we have the explanation of the great richness of these deposits to extraordinary depths.

As a case of sulphide deposits which continue to great depth without diminution in richness, may be mentioned the gold-quartz veins of Nevada City and Grass Valley, California. According to Lindgren, "it can be confidently stated that there is no gradual diminution of the tenor of the ore in the pay-chutes below the zone of surface decomposition,"* although within the same chute there are many and great variations in richness. This statement is applicable to deposits which reach a vertical depth of 500 or 600 meters. If Lindgren is correct in thinking the gold-quartz veins of the Sierra Nevada do not diminish in depth below an extremely superficial upper zone, this would be a case in which sulphuret ores were sufficiently concentrated by ascending waters alone to afford workable ore-deposits.

THE PRECIPITATION OF ORES BY ASCENDING AND DESCENDING WATERS COMBINED.

Thus far we have considered ores precipitated by ascending waters alone. However, many of the ores thus produced have been profoundly modified by the action of descending waters.

Where the point of exit of the ascending waters of the trunk channels is in a valley or near the level of surface drainage, the waters may continue to ascend quite to the surface. However, where the openings are below slopes the waters ordinarily do not continue to ascend to the surface, but make their way laterally from the trunk-channel at and below the level of groundwater (see Fig 6). Above the level of groundwater, and frequently for a certain distance below the level of groundwater, the movement is downward in the openings. The water

* "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann Rept U S Geol Surv*, pt 11, 1895-96, p 163

thus moving downward includes not only that which directly passes into the trunk openings at the surface, but a much larger quantity which converges into these openings from the smaller openings on all sides.

In regions in which mining is going on, denudation has ordinarily truncated the veins for considerable depths, in many cases to hundreds or even thousands of meters. It is therefore clear, in a majority of cases, that portions of the fissures in which the waters are now descending were, in the past, in all probability much deeper below the surface, and therefore the waters at that time in the larger fissures were probably ascending. During the time the water was ascending, the first concentration of sulphurets and other products took place. But as a result of the downward migration of the belt of weathering and the downward movement of water in that belt, alteration and secondary concentration of ore-deposits have taken place. This second concentration of ore-deposits is of the very greatest importance, and I believe largely explains the frequent greater richness of the upper 50 or 100 or 500 meters, and in some cases 1000 meters, as compared with lower levels.

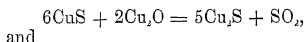
It has already been pointed out that the descending waters bear oxygen and carbon dioxide; and furthermore, that solution is taking place. Moreover, the belt of weathering is migrating downward because of erosion. The result of all these changes is to produce an upper belt of second concentrates from the first concentrates formed by ascending waters. This material may be divided into three parts (1) above the level of groundwater is a belt largely composed of oxides, carbonates, chlorides and associated products, which, however, may contain enriched sulphides (2) Above and below the level of groundwater is a transition belt composed of sulphides rich in the valuable metals, such as gold, silver, copper, lead and zinc, which, however, contain subordinate amounts of oxidized products (3) Deeper down is a belt of lean sulphides bearing small amounts of the more valuable sulphurets, and which commonly passes into iron sulphide. Between the three classes of material there are gradations. The oxidized belt gradually passes into the rich sulphide belt; the rich sulphide belt gradually passes into the poor sulphide belt.

The above results are due to a complicated set of reactions

which cannot here be given in full. It is, however, clear that if the sulphides are equally abundant the sulphide which is the most easily oxidized will be the first to disappear. The order of disappearance will therefore be iron, copper, zinc, lead, silver. It is, however, understood that the oxidation of an easily destroyed sulphide is not complete before the oxidation of a refractory sulphide has begun. All of the sulphides are oxidized all the time, but the more readily a sulphide is oxidized, the more rapidly it is destroyed. During oxidation the sulphides are largely altered to soluble sulphates, which are taken into solution and carried downward.

The evidence of the extensive formation of sulphates in veins by descending water is found in the presence of sulphates in mine waters and in the frequent formation and precipitation of basic ferric sulphate in the veins, as, for instance, at Cripple Creek,* and in the Mercur district, Utah †. The formation of gypsum and magnesium sulphate in veins is scarcely less positive evidence of the oxidation of the sulphides to sulphates. Further evidence of the formation of sulphates by oxidation of the sulphides is furnished by the hydrous sulphate of aluminum which occurs in the gold-veins of California ‡.

The sulphides, however, are not all oxidized to sulphates, a portion of them, by oxidation, break up into sulphurous oxide and oxides of the metals. A part of the oxides unite with the carbonic acid to produce carbonates. Finally the oxides and oxidized salts, both formed in place and transported, react upon the unaltered sulphides, producing richer sulphurets. The reactions may be between an oxide or a salt of a metal and its sulphide, as, for instance, the oxide or sulphate of copper upon the sulphide of copper, as given by the following equations



and



* "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Surv., pt. 11, 1894-95, p. 130.

† "Economic Geology of the Mercur Mining District, Utah," by J. Edw. Spurr, 16th Ann. Rept. U. S. Geol. Surv., pt. 11, 1894-95, p. 433.

‡ "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17th Ann. Rept. U. S. Geol. Surv., pt. 11, 1895-96, p. 120.

Or the reaction may be between the oxide or salt of one metal and the sulphide of another metal, as, for instance, copper oxide or copper sulphate upon iron sulphide, thus precipitating copper sulphide. The particular reactions in an individual case will depend upon the relative solubilities of the compounds present, and the law of mass-action. This will more clearly appear upon subsequent pages

The concentrations by ascending and descending waters have been considered as if they were successive. In some instances this may be the case; but frequently it is much more probable that ascending and descending waters are at work upon the same fissure at the same time, and that their products are, to a certain extent, simultaneously deposited. For instance, under the conditions represented by Fig 6, a first concentration by ascending waters is taking place in the lower part of the fissure, and a second concentration by descending waters is taking place in the upper part of the fissure. Between the two there is a belt in which both ascending and descending waters are at work. The rich upper part of an ore-deposit which is worked in an individual case may now be in the place where ascending waters alone were first acting, where later, as a consequence of denudation, both ascending and descending waters were at work, and still later, where descending waters alone are at work. The more accurate statement for this class of ore-deposits, therefore, is that ascending waters are likely to be the potent factor in an early stage of the process, that both may work together at an intermediate stage, and that descending waters are likely to be the potent factor in the closing stage of the process

The above general statement may perhaps be better understood if supplemented by a consideration of specific associations of the metals. The associations which are chosen for illustrative purposes are as follows (1) associations of lead, zinc and iron, (2) associations of copper and iron, (3) associations of silver and gold with the base metals.

THE ASSOCIATION OF LEAD, ZINC AND IRON COMPOUNDS.

In order to understand the relations of the lead, zinc and iron compounds where they occur together in ore-deposits, it seems advisable to take an individual district rather than to make a general statement. An excellent illustration of the

association of these metals is furnished by the Upper Mississippi Valley, and this district will therefore be considered.

Facts of Occurrence.

Here, as is well known, in openings in limestones, lead and zinc minerals are associated with marcasite, and some pyrite and chalcopyrite.* Calcite is an abundant gangue mineral, as would be expected, but it and the other gangue minerals will here not be taken into account. Since the pyrite and chalcopyrite are very subordinate, they will not again be alluded to. All of the sulphide of iron will be referred to as marcasite.

The order of occurrence in the district is commonly as follows. Above the level of groundwater in the belt of weathering the dominant valuable minerals are galena and smithsonite. Frequently encrusting the galena, or in crystals upon it, there are some cerussite and less anglesite, with the smithsonite there is some sphalerite. The smithsonite may extend 5 or 10 meters below the level of groundwater; but deeper the oxidized products almost wholly disappear. The smithsonite below the level of groundwater is explained in some cases by the material being along a main channel of downward percolating waters; in other cases by the fact that the level of groundwater is probably now higher than it once was, as a result of depression and valley-filling at the close of the glacial epoch, thirdly, by the well-known general downward movement of oxidizing water somewhat below the level of groundwater, and, fourthly, by reactions between oxidized lead salts and the sphalerite. (See p. 106.) Below the galena and smithsonite is sphalerite, with a large amount of marcasite†. For much of the district the workings have not extended far below the level of groundwater, but in certain parts of the district working has extended for a considerable depth.

While the above general statement is correct for much of the district, it must be understood that a single sulphide does

"The Ore-Deposits of Southwestern Wisconsin," by T. C. Chamberlin, *Geol. of Wis.*, vol. iv, 1882, pp. 380-393.

† Chamberlin emphasizes the inferior position of the zinc as compared with the lead and the association of the zinc and iron, but he does not consider the positions of these compounds with reference to the level of groundwater. *Loc. cit.*, pp. 488-491.

not occur at a given level to the exclusion of the others. Indeed, in many cases all of the sulphides are found at the same level. In many of the smaller veins the sulphides occur in a definite order. The full succession at various openings, from the wall to the druse, is (1) marcasite, (2) ferriferous sphalerite, (3) galena, in cubic crystals, (4) ferriferous sphalerite (subordinate in quantity), (5) marcasite, (6) galena, in octahedral crystals (very subordinate in quantity) *. Of this succession at various veins some of these elements are lacking. A very common order is (1) sphalerite, (2) galena, and (3) marcasite.

First Concentration

No clearer possible illustration could be found of the general principles of ore deposition by the underground waters, and the phenomenon of crustification emphasized by Posepny, than that furnished by this district. The first concentration is believed to be the work of ascending waters, the materials being precipitated in the form of sulphides. It is probable that there was a tendency at the time of the original crystallization for the sulphides to be thrown down in a definite order across the openings, as shown by the phenomena of crustification. Furthermore, it appears that there may have been two main cycles of precipitation, so far at least as the sphalerite and galena are concerned, but the first cycle was by far the more important. It is also possible that there was a tendency for the sulphides to be precipitated in a definite order vertically, as a consequence of which the marcasite was the predominate precipitate at the lowest level, sphalerite at the intermediate levels, and galena at higher levels. Such an order might be explained as a result of the lessening pressure and temperature as the depositing solutions rose in the openings.

Second Concentration.

While it is possible that the vertical order of the minerals is due to a first concentration, it is probable that this is not the most important factor in the regular vertical distribution of the sphalerite and galena. It is believed that the present general order of these materials is mainly controlled by the downward-moving waters combined with denudation

* Chamberlin, *loc cit*, pp 491-497.

It is not necessary to show that the smithsonite above and a short distance below the level of groundwater was largely derived from sphalerite, and that the cerussite and anglesite were largely derived from galena. The details of the relations of the various oxidized and sulphuretted minerals above the level of groundwater are exceedingly complex, and no description of them will here be attempted. Nor in this paper is it necessary to write reactions for the transformation of the sulphides into the oxidized products, since the general characters of such reactions are so well known.* It is, however, necessary to explain how downward-percolating waters may concentrate galena at a high level and sphalerite at a lower level.

Galena —If it be premised that the ascending waters evenly distributed the sulphides, at least so far as the vertical element is concerned, it is certain that downward-moving waters, combined with denudation, may concentrate the galena at high levels and the sphalerite at lower levels.

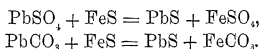
The galena is the most difficultly oxidizable of the three sulphides. It is, therefore, the most stable of them. By the oxidation and solution of the sphalerite and marcasite above the level of groundwater the galena would be concentrated. That this process has taken place on an extensive scale is shown by the occurrence of many detached fallen crystals and masses of galena in the openings above the level of groundwater, and also at the bottoms of the wider openings and caves a short distance below the level of groundwater. Indeed, a considerable portion of the lead of the district which has been taken above or within a few feet below the level of groundwater strongly corroborates the idea of concentration as result of solution of the other sulphides which held the galena to the walls, thus permitting the material to drop to lower positions in the crevices †

While the concentration of the galena is partly explained as above, it may be explained also in part by chemical reactions between the various compounds. In the belt of weathering part of the galena as already noted is being oxidized, as is shown by the incrustations and superimposed crystals of cerussite and anglesite. During the formation of the sulphates and

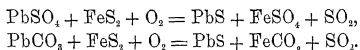
* Chamberlin, *loc. cit.*, pp. 497-509

† Chamberlin, *loc. cit.*, pp. 453 to 497

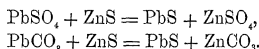
carbonates, a certain amount of these salts is taken into solution and carried downward. These sulphates and carbonates would react upon the other sulphides present and reprecipitate the lead as galena. These reactions might take place to some extent above, but would be especially likely to occur below, the level of groundwater. As a result of the downward migration of the belt of weathering, there would be in the downward-moving waters a continual supply of the sulphates and carbonates of lead. The chief reaction would be that between the lead salts and the dominant iron sulphide. Supposing the iron were in the form of FeS , the reactions may be written as follows:



If the iron be supposed to be in the form of FeS_2 , as is most likely, oxygen also would be necessary for the reactions. The equations would then be as follows:



However, it has been premised that with the original sulphides zinc sulphide is present, and this may also react upon the lead salts, according to the following reactions:

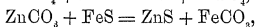
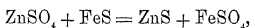


In the case of the latter reaction, smithsonite would be formed. In this connection it is notable that frequently associated with the galena for some distance below the level of groundwater, smithsonite occurs, as already noted. While a part of the smithsonite below the level of groundwater is of this origin, doubtless the larger portions of it are differently explained (See p. 103.)

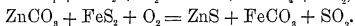
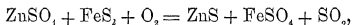
To the foregoing reactions, partly explaining the concentration of galena, objection may be made upon account of the small solubility of lead sulphate and lead carbonate. It is true that these substances are very sparingly soluble in pure water; however, they are sufficiently soluble in waters bearing carbon-dioxide to account for the phenomenon. If this be not the case, the lead may have been carried downward as chloride.

Independent, however, of chemical theory, we know in many districts, and particularly in the lead and zinc district of southwestern Wisconsin, that the galena has been changed to some soluble form upon an extensive scale. As evidence for this inference, galena crystals above the level of groundwater are much corroded, and the amount of cerussite and anglesite associated with them is so small as not to account for the corrosion, and therefore the lead has been transformed to a soluble salt, which has been transported below in important amounts *. So far as my argument is concerned, it is of no consequence whether the lead is as a sulphate, carbonate, chloride or other salt. However, it is believed that these are the forms in which the lead was transferred on the most extensive scale. I regard the cerussite and anglesite as evidence of the partial transfer of the lead as sulphate and carbonate. A large amount of sulphate and carbonate probably formed, but the compounds are so insoluble that a part of the salts produced were not carried downward, but precipitated near the places of formation.

Sphalerite.—Zinc holds sulphur less strongly than lead, but much more strongly than iron. Therefore, the sphalerite would be concentrated in the zone below the galena, the reactions being similar to those producing the galena. They may be written as follows



or



Marcasite.—At a certain depth in the openings below the level of groundwater, nearly all of the salts of lead and zinc descending from the belt of weathering would be precipitated by reactions between them and the iron sulphide, as above explained. The remainder of this paragraph cannot be said to apply to the deposits of the upper Mississippi Valley; for the vertical extent of the veins is probably very limited, many of them apparently being cut off by impervious strata within short distances from the surface. However, in veins in which the

* Chamberlin, *op. cit.*, pp 498-499, 500

first concentration extends to a depth greater than that to which downward-moving waters are effective, only the sulphurets of the first concentration would be found below this level. These sulphurets would consist mainly of marcasite, with subordinate amounts of sphalerite and galena. However, even in this belt, concentration of galena and sphalerite may occur to some extent, although it receives no contribution from the lead and zinc salts from above, for even after the salts of lead and zinc traveling downward from the belt of weathering are all precipitated, the waters may still hold oxygen. This oxygen would, to the largest extent, act upon the marcasite, producing to some extent soluble salts which would be abstracted, and thus reduce the quantity of this material, and relatively enrich the deposits in lead and zinc, although not increasing the absolute amount of lead and zinc present in a given vertical distance. So far as the zinc and lead salts were oxidized by the oxygen-bearing water, these would react upon the iron sulphide again, and they would be precipitated according to the reactions above given.

General

It is believed that the concentration by descending waters explains, through the reactions given on pp. 106-107, the orderly distribution of the ores in a vertical direction,* although original deposition by ascending waters may have produced its effect. Furthermore, it is believed that this concentration was the final determinative factor in making the ores so rich as to warrant exploitation. This statement in reference to the rich deposits applies both to the oxidized products and to the sulphurets, both above and below the level of groundwater. This process of concentration is primarily chemical, but also to some extent is mechanical, the latter being especially true of the galena loosened by solution from the walls which have fallen to the lower positions in the crevices and caves.

While the reactions of the downward moving oxidized products upon low grade sulphurets, thus producing rich sulphides, have been dwelt upon, it is not supposed that these are the only reactions which have resulted in enrichment. As pointed out by Chamberlin,† organic matter has made its way into the

* Compare Chamberlin, *op cit*, pp 551-553

† Chamberlin, *op cit*, p 544.

openings of the limestone, and as further indicated by Chamberlin,* and emphasized by Blake,† organic matter is abundant in certain of the shaly layers. As argued by Chamberlin and Blake, organic material in the rocks from both of these sources was probably an important factor in the reduction and precipitation of the downward moving sulphates. As pointed out by Blake, the evidence of the effect of this organic matter is especially clear in the cases of the large sphalerite deposits which rest upon the oil-rock at the top of the Trenton as a floor.

My own views in reference to the concentration of the ores in the upper Mississippi valley differ somewhat from those of Chamberlin,‡ Whitney,§ and others, who have held that these ores are products of descending and lateral-secreting waters alone, but still more from those of Percival|| and Jenney,¶ who have held that the ores were derived from a deep-seated source. The first supposed the transportation to have taken place through igneous, the second through aqueous agencies. Since the discussion of this difference of view involves the influence of some of the special factors considered later, it is deferred to pp. 142-150.

Therefore, so far as practicable, the above statement concerning concentrations by ascending and descending waters and the reactions of the sulphates upon the sulphides is made without reference to the special features of the upper Mississippi valley district. This procedure has been followed because it is believed that in many of the lead and zinc districts of the world the above statement is applicable in its main features.

THE ASSOCIATION OF COPPER AND IRON COMPOUNDS.

Another very general association of metals is that of copper and iron. It is well known, where this association occurs, that

* Chamberlin, *op cit*, p 546

† "Lead and Zinc Deposits of the Mississippi Valley," by Wm. P. Blake, *Trans A I M E*, xxii, pp 630-631 "Wisconsin Lead and Zinc Deposits," by Wm P. Blake, *Bull G S A*, vol v, 1894, pp 28-29

‡ Chamberlin, *op cit*, pp 544-549

§ Whitney, "Geol of Wis," vol. 1, 1862, pp 398, *et seq*

|| Percival, "Ann Rept Geol Surv of Wis," 1855, pp 30-33, "Ann Rept Geol Surv of Wis," 1856, p 63

¶ Jenney, "Lead and Zinc Deposits of the Mississippi Valley," *Trans Am Inst Min Eng*, vol xxii, 1894, pp 210-223

above the level of groundwater, cuprite (Cu_2O), tenorite (CuO), azurite (2CuCO_3 , $\text{Cu}(\text{OH})_2$) and malachite (CuCO_3 , $\text{Cu}(\text{OH})_2$) are very frequently found. It is further very well known that below the level of groundwater these oxidized and carbonated products occur in greatly diminished quantity, and that rich sulphurets frequently occur, such as chalcocite (Cu_2S), bornite (Cu_5FeS_4) and chalcopyrite (CuFeS_2), and sometimes covellite (CuS). Somewhat deeper below the level of groundwater the oxides and carbonates are not found. Furthermore, the chalcocite, covellite and bornite are very generally restricted to the upper part of the belt of groundwater, deeper, the places of these minerals are largely occupied by chalcopyrite. Not only this, but still deeper the chalcopyrite is less prominent in many instances, and the iron sulphides more prominent. In the lower workings of many of the deeper mines the only metalliferous product found is cupriferous iron sulphides, the chalcopyrite having wholly disappeared.

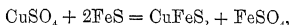
Whether or not this general statement is correct for a particular area, each mining engineer can judge from his own knowledge. There may be exceptions to it, due to various causes, one of which has been alluded to in explaining bonanzas. Thus below cupriferous pyrites there may again be found richer copper sulphides. Indeed, as before stated, ore-deposits vary greatly in their richness both horizontally and vertically,* and the above statement can only be considered as a general average.

The above order is believed to be explained by the work of downward-moving waters. The combinations of lead, zinc and iron were followed from above downward. The reactions which occur in the case of the copper-iron deposits we may perhaps follow, to vary the order, from the base upward. At greater or less depths below the level of groundwater the ores are frequently cupriferous pyrites, the direct deposit of the ascending waters. At a little higher level oxygen from above may have oxidized a portion of the iron and transported it elsewhere, thus relatively enriching the deposit in copper. At a still higher level there will be a contribution of soluble copper salts from above. Since copper sulphate would certainly be the

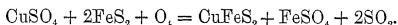
* *Trans.*, xxiv., 991-992.

most common salt, for convenience all the soluble salts will be regarded as sulphates. Reactions similar to those given below may easily be written for other salts

At the level where salts of copper appear from above, by the reaction of the copper salt upon iron sulphide, chalcopyrite may be produced, the reactions following from the fact that copper-iron sulphides are less soluble than iron sulphides, and from the law of mass action. The reactions may be written as follows.

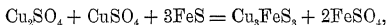


or

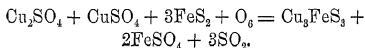


Where the iron sulphide is pyrrhotite, intermediate between FeS and FeS₂, the reactions may be written by combining the above equations in proper proportions.

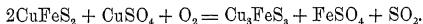
In passing upward from the lowest level at which the chalcopyrite appears, this mineral may steadily increase in quantity until it becomes an important constituent, and finally the iron sulphide may become subordinate. Under these circumstances bornite is likely also to appear. The production of bornite by the direct reactions of the copper salts upon iron sulphide may be supposed to be as follows.



or



However, the bornite may also be produced by the reaction of the copper salt upon the chalcopyrite itself. For instance:



Reactions might also be written for the production of the bornite from the chalcopyrite by the reaction of cuprous sulphate and oxygen. Further reactions might be written as result of which the bornite is derived from chalcopyrite and iron sulphide together; but it is hardly worth while to do this, since no new principle is illustrated.

Passing to still higher levels, with the chalcopyrite and

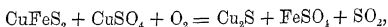
bornite chalcocite may appear. The chalcocite may be produced directly by the reaction of cuprous salt upon iron sulphide, as follows.



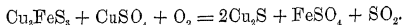
or



Furthermore, the chalcocite may be produced by reactions of the sulphates either upon the chalcopyrite or upon the bornite. In the first case the reaction may be written as follows



or from the bornite by the following reaction



Of course, it is understood that these sulphides overlap one another. Before the iron sulphide has wholly been replaced by chalcopyrite, bornite may appear. At the place where bornite has become reasonably abundant, chalcocite may be found. However, certain general statements may be made. If the dominating material is iron sulphide, the copper mineral which is present is likely to be chalcopyrite rather than the richer sulphurets. Chalcopyrite, on the one hand, is likely to be associated with the pyrites, and on the other hand with bornite, or even chalcocite. Bornite and chalcocite are likely to be associated with each other and with chalcopyrite, but with the first two compounds iron sulphide is likely to be subordinate or absent.

At still higher levels in a mine, a moderate distance below the level of groundwater, oxidized and carbonated products may appear with the sulphurets. These mixed products, sometimes called oxysulphurets, are well illustrated in the Appalachian, Arizona and Montana deposits.* Still higher, and especially above the level of groundwater, the oxidized products may become dominant, for there the rich sulphurets which have emerged from the level of groundwater have been directly acted upon by the oxygen and carbon-dioxide. A

* "The Copper Resources of the United States," by James Douglas, *Trans.*, XIX, 1891, 690, *et seq*

series of transformations now take place which may result in metallic copper, cuprite, tenorite, azurite and malachite. As in the case of the lead and iron, the nature of these reactions is so well known that they will not here be written out. The oxidation of the sulphur and copper may be simultaneous, or the sulphur may be oxidized first, forming metallic copper, which may later be oxidized in whole or in part. The oxidized products may be first the oxide, cuprite. This may be altered to tenorite, and this, later, may unite with carbon-dioxide and water to form the hydro-carbonates, azurite, and finally, by further hydration, malachite. Illustrating this process, Prof Penrose has shown me, in a single hand-specimen from the oxidized belt of the Arizona mines, concentrically arranged metallic copper, cuprite, tenorite, and carbonate of copper, the copper being in the core and the carbonate of copper on the outside. The oxidized products may largely remain in place, furnishing rich ores, or they may be almost wholly dissolved and carried to lower levels, to react upon the sulphides, as already explained.

Therefore, largely by processes of oxidation and reaction upon sulphurets, first forming rich sulphurets and later rich oxidized products, there may be concentrated in the upper few, or few score, or few hundred meters of a vein, a large part of the copper produced by a first concentration through a much greater distance. Since the reactions already considered are not the only ones which enter into the second concentration of rich deposits, individual illustrative cases are deferred until after the other factors are considered. (See pp 128-134.)

By the foregoing it is not meant to imply that each copper sulphide deposit has gone through the entire history above detailed. Indeed, there is no doubt that the general story outlined will need much modification when applied to an individual case. However, it is held that some process of secondary concentration similar to that outlined has been a very important factor in the production of rich copper deposits at many localities.

THE ASSOCIATION OF SILVER AND GOLD WITH THE BASE METALS.

The two common cases of the association of lead, zinc and iron, and that of the association of copper and iron, have now

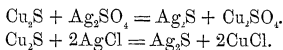
been considered. A similar set of transformations can be traced out in either of these classes of deposits which contain associated silver and gold.

Silver.

In the case of silver, it is well known that the original forms are generally sulphides, sulphantimonites, sulphantimonates, sulpharsenites, and sulpharsenates. Silver sulphide is a compound which holds strenuously to its sulphur. Ordinarily it is not sufficiently abundant to constitute the main mass of an ore-deposit. However, since it holds so strongly to its sulphur, the silver salts are likely to be found, in the case of lead-zinc-iron compounds, most abundantly with the lead, less abundantly with the zinc, and least abundantly with the iron; and in the case of the copper-iron compounds, most abundantly with the copper and less abundantly with the iron. The rich silver compounds, viz., native silver, cerargyrite (AgCl), argentite (Ag_2S), proustite (Ag_3AsS_3), pyrargyrite (Ag_3SbS_3), stephanite (Ag_3SbS_3), may be abundantly found in the upper parts of mines, but frequently decrease in amount in passing from the surface deep into the zone of sulphides, and at sufficient depth in this zone these silver minerals may entirely disappear, the products being wholly argentiferous lead, zinc, copper, and iron minerals. In many cases independent silver minerals do not occur at all, all of the silver being in the lead, zinc, copper, and iron compounds. In the case of the lead, zinc, and iron deposits, as the ores become poorer in lead and zinc, they are also likely to become poorer in silver. Also, in case the copper-iron deposits become poorer in copper with depth, the silver will also ordinarily decrease in amount. Therefore the plumbiferous and zinciferous pyrites and cupriferous pyrites deep down are ordinarily lower in silver than the deposits above, which are richer in the base metals.

In this general paper it is hardly worth while to write the reactions for the production of the rich silver sulphurets. Since silver holds to its sulphur more strenuously than any of the base metals with which it is associated, the first of these baser metals which is met in mass will be reacted upon by the silver salts. Suppose, for instance, that in the belt of weathering the silver sulphide is oxidized to silver sulphate or changed

to silver chloride. The first of the salts and the second to some extent are taken into solution and pass down where they may come in contact with chalcocite. Argentite would then be precipitated according to the following reactions:



In a manner similar to the treatment of the other salts, various other reactions could be written between salts of silver and the other sulphides of copper, lead, zinc and iron. For the present purposes, it is only necessary to understand that the silver will be concentrated either as an independent silver sulphuret or as a silver sulphide associated with the rich sulphides of the base metals.

As a case in which silver is concentrated in a sulphide rather than in the carbonate, may be mentioned the Leadville ores. Here, according to Emmons, the galena is much richer in silver than the cerussite. Not only is this so in general, but there are some very interesting special cases. For instance, in the case of five assays of galena nodules which had carbonate crusts, "there are six times as much silver in the galena as in the cerussite."* This discrepancy may be partly explained by the abstraction of the silver as sulphate from the lead carbonate, but I suspect it to be mainly explained by the reaction of the oxidized silver salts upon the galena, producing a galena richer in silver than originally existed.

Above the level of groundwater the silver occurs to some extent in the native form, but more largely as cerargyrite. Silver does not readily unite with oxygen, hence the explanation of the metallic form. However, it does have a strong affinity for chlorine, and where that element is present cerargyrite is likely to be found.

Where the silver is largely changed to the sulphate and chloride, and is not largely precipitated as cerargyrite, the upper part of the silver veins in the belt of weathering may be greatly depleted in silver as a result of this leaching process. That the silver is not thrown down as cerargyrite may be due to a

* "Geology and Mining Industry of Leadville," by S. F. Emmons, Mon. No. 12, *U. S. Geol. Surv.*, 1886, pp. 553-554.

deficiency of chlorine in the descending solutions, or to the fact that the solutions are of such a character or so abundant that they are capable of dissolving the silver chloride. Probably illustrating this process of depletion is the Cripple Creek district, where the upper parts of the veins which carry free gold are deficient in silver, while the original telluride contains a certain amount of silver, showing that the silver has probably been leached out.*

Gold

Gold occurs extensively (1) in the native form, (2) associated with the sulphides, and (3) as a telluride.

In the belt of weathering, gold is very largely found in the metallic form associated with the oxidized products of the base metals, and especially with oxide of iron. Much of such gold has plainly been associated with sulphides or has been united with tellurium.

Below the level of groundwater the most common associations of gold are the sulphides of the base metals. Where base metals other than iron do not occur, gold occurs associated on a great scale with pyrite. In such associations, where the sulphides are abundant, the gold is likely to be plentiful; where the sulphides are deficient, the gold is also likely to be deficient †. This relation is illustrated both by California and Australasia. The relation suggests that the original solution and deposition of native gold is frequently connected with that of the sulphides, and therefore it is reasonable to infer that the same conditions which produced sulphides also resulted in the solution and precipitation of gold.

In various districts in the Cordilleran region, and especially in Colorado, and more particularly in the Cripple Creek district, the original form in which much of the gold was deposited is a telluride ‡.

* "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Surv., pt. II, 1894-95, pp. 131-132.

† "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17th Ann. Rept. U. S. Geol. Surv., pt. II, 1895-96, pp. 124-126. "The Genesis of Certain Auriferous Lodes," by J. R. Don, *Trans.*, xxvii, 1898, 567.

‡ "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Surv., pt. II, 1894-95, pp. 119-121.

The original form of the gold of the Judith mountains* is also a telluride. Telluride of gold further occurs in the gold-belt of California,† in the mines of Custer county, Colorado,‡ and in western Australia,§ associated with sulphides. Pearce suggests|| that the free gold which occurs in various regions may have been originally deposited as a telluride which was later oxidized in the belt of weathering. The Cripple Creek district, in which the gold in the weathered zone is in the metallic form,¶ furnishes an excellent illustration of the formation of free gold from a telluride.

From the foregoing it is plain that gold may be originally precipitated by ascending solutions in a vein as metallic gold, as a telluride, or partly in both forms. Moreover, either one or both of these forms may be associated with the sulphides of the base metals.

Nothing has thus far been said as to the form in which the gold is transported. However, it is certain that gold is soluble in the various underground solutions, and especially in the alkaline sulphides. Moreover, gold readily makes combinations with iodine and chlorine, and as an iodide and chloride is easily soluble. Also alkaline iodides are capable of dissolving gold.** Furthermore, gold is soluble in ferric sulphate. That gold and the salts of gold—one of which we know to exist in nature as a solid, the telluride—are soluble in underground solutions is the main point. Since the modern ideas of physical chemistry have been developed, the form in which the gold is carried is put in a new light. It was supposed that it must be regarded as united with one or more of the other ions present. Since underground solutions of gold are exceedingly dilute, it is highly probable that the gold is ionized or is

"Geology and Mineral Resources of the Judith Mountains of Montana," by W. H. Weed and L. V. Fisson, *18th Ann. Rept. U. S. Geol. Surv.*, pt. iii, 1896-97, pp. 589, 591, 597.

† Landgren, *op. cit.*, p. 117.

‡ "The Mines of Custer County, Colorado," by S. F. Emmons, *17th Ann. Rept. U. S. Geol. Surv.*, pt. ii, 1895-96, p. 433.

§ "The Superficial Alteration of Western Australian Ore-Deposits," by H. C. Hoover, *Trans.*, xxviii, 1899, 762.

|| *Proc. Colo. Sci. Soc.*, vol. ii, 1885, pp. 1-6.

¶ Penrose, *op. cit.*, p. 119-120.

** "The Origin of the Gold-bearing Quartz of Bendigo Reefs, Australia," by T. A. Rickard, *Trans.*, xxii, 1894, pp. 308-309.

in the free state. Thus regarded, it would be kept in the ionic state not by any one of the associated acid ions present, but partly by all of them. While the above is true, it is also doubtless true that certain solutions are much more capable of dissolving gold and gold salts than others, and upon this point further investigation is needed.

In whatever form gold is carried, it is known to be precipitated in the first concentration as a telluride, or as metallic gold associated with tellurides or sulphides, or both. Whether it is also precipitated as a sulphide is uncertain. Too little is known about the tellurium salts or the origin of the tellurides to enable one to make any statement concerning the precipitation of gold in this form. However, it is comparatively easy to suggest agencies which may have resulted in the precipitation of gold in the metallic form. When it is remembered that copper is extensively precipitated in the metallic form in the Lake Superior region, and that gold is even more readily reducible, the frequent precipitation of gold in the metallic form need occasion no surprise. Gold would be precipitated in the metallic form by organic matter or by any *ous* salt.

Rickard* calls attention to the frequent association of metallic gold with sedimentary rocks bearing organic matter in Colorado, California, New Zealand, Australia and Tasmania †. The most remarkable case is the concentration of gold in veins where they cross strata of carbonaceous shale, called indicators. Says Don,‡ "Away from the indicator, the greater part of the vein quartz is absolutely barren; but at the intersection with the indicator larger masses of gold (often more than 100 ounces in one piece) have been obtained, and the greater part of the gold extracted from this belt has come from those parts of the quartz veins near some one of the indicators." Furthermore, Rickard§ describes experiments in which the black carbonaceous shale of Rico was placed in silver solutions and in solutions containing Cripple Creek gold-ore.

* *Trans*, xxii, 314-315.

† "The Indicator Veins, Ballarat, Australia," by T. A. Rickard, *Eng and Min Journ*, vol ix, 1895, pp. 561-562.

‡ "The Genesis of Certain Auriferous Lodes," by J. R. Don, *Trans*, xxvii., 1893, p. 569.

§ "The Enterprise Mine, Col.," by T. A. Rickard, *Trans.*, xxvi, 1897, pp. 973-979.

Both metallic silver and gold were abundantly precipitated upon the shale in a short time. In the instances above mentioned it can hardly be doubted that the organic material was an important or controlling factor in the reduction and precipitation of the gold.

Gold would also be precipitated from solutions which came in contact with ferrous oxide, such as magnetite, or by solutions bearing ferrous or cuprous sulphate, or any other ferrous or cuprous salts. When it is remembered that *ous* salts are extensively produced underground (see pp 93-94), it becomes highly probable that such solutions are frequently the cause of the precipitation of gold with sulphurets. Since iron is the most abundant of all the metals carried in underground solutions, such sulphates would be more likely to be sulphates of iron than any other. If the salts formed in the belt of weathering were ferric sulphates, they would be likely to be reduced to the ferrous condition at depth by the ferrous iron, which is especially abundant in the basic rocks. Indeed, analyses of mineral waters which bear sulphates also ordinarily show ferrous iron.* Therefore ascending waters bearing ferrous sulphate or other *ous* salt might be brought into a lode by side-streams and there precipitate the gold. Such side-channels entering through lateral cracks may, in many cases, explain the extreme irregularity of the distribution of the gold.

Although Lindgren argues to the contrary in the Sierra Nevada,† the suggestion that a part of the gold there has been reduced by ferrous sulphate has extreme plausibility. The gold associated with the pyrites is native. In that district two analyses of the waters of feeding-streams (the only analyses reported) entering the lodes at a depth of 400 feet are given. Both of these analyses show that sulphates and iron are present.‡ According to the analyses the iron is reported as ferric; but apparently no precautions were taken, when the waters were collected, to prevent the oxidation of ferrous to ferric iron. Indeed, the description of the deposits made by the underground springs renders it highly probable that ferrous salts were there contained,

* "Mineral Waters of the United States," by A. C. Peale, *Bull U S Geol Surv*, No 32

† Lindgren, *op cit*, p 181, and pl v, p 184

‡ Lindgren, *op cit.*, pp. 121-123.

as shown by the precipitates of yellow material, which is partly ferric oxide. Moreover, if these analyses are not sufficient evidence of the presence of sulphates, the clean vein quartz itself, which contains a large number of fluid inclusions, contains sulphates,* showing that sulphate-bearing waters are not exceptional, but must have been present at the time the lodes themselves were formed. Finally, the ore-shoots have great irregularities in richness, for which Lindgren offers no explanation. The suggestion above made that the gold is precipitated in the metallic form by the reducing action of ferrous sulphate explains all of these facts. The deposits are rich where the side-springs issued from cross-fissures and furnished ferrous sulphate to the ascending waters. The gold is in the metallic form because reduced by the ferrous sulphate.

The argillite with which many of the gold-ores of the Sierra Nevada are associated is carbonaceous,† and this carbonaceous material may have assisted in the production of the *ous* salts which ultimately reached the trunk-channels. Indeed, in some places, as, for instance, where the pyrite occurs in a carbonaceous argillite but not in quartz,‡ the gold may have been directly precipitated by the carbonaceous material. But since the gold in the Sierra Nevada is mainly deposited in open fissures,§ the suggestion of reduction of the major portion of the gold by *ous* salts, and especially ferrous sulphate, is thought to be the more plausible, although, as already explained, the formation of the ferrous sulphate may be due in part to carbonaceous material in the country-rock

It can hardly be doubted that, after a first concentration of gold has taken place, as consequence of descending waters a second concentration may take place. But definite equations cannot be written until it is determined in what form the gold is transported. However, if in the solutions we do not know the acids against which the gold is balanced when transported downward, we may feel sure that, when such solutions reach the sulphide zone, there will be reactions between the acid

* Lindgren, *op cit*, pp. 130-131, 260, 261

† "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17th *Ann. Rept. U S Geol. Surv.*, 1895-96, pt. 11, p. 81, 1896.

‡ Lindgren, *op. cit.*, p. 140, pl. viii

§ Lindgren, *op cit*, p. 259

ions balancing the gold and the bases in the tellurides and sulphides. As a consequence of these reactions metallic gold, and possibly tellurides and sulphides, will be precipitated in a manner similar to that of the precipitation of copper. Individual cases of second concentrations will be considered after other factors influencing concentration have also been dealt with. (See pp 128-134)

CONCENTRATION BY REACTION UPON SULPHIDES COMPARED WITH METALLURGICAL CONCENTRATION

One of the more common processes of metallurgy for the separation of gold, silver, copper and lead from iron is based upon the principle explaining the second concentration given on preceding pages, viz, that iron holds sulphur less strongly than the other elements named. The sulphuretted ores are imperfectly roasted, thus partly oxidizing them to oxides and sulphates. The ores are then smelted in a furnace with a flux. The oxides of the valuable metals and the sulphates react upon the remaining sulphides of all the metals, producing a matte containing the sulphides of the valuable metals. The iron gets all or nearly all of the oxygen, and the iron oxide unites with the fluxes and passes into the slag.

OTHER REACTIONS OF DESCENDING WATERS.

In the foregoing pages the second concentration of metals by solution, downward transportation and precipitation by reactions upon the sulphides of the first concentration has been emphasized. However, it is not supposed that this is the only process which may result in enrichment in the upper parts of vein deposits by descending waters. The enrichment of this belt may be partly caused (1) by reactions between the downward moving waters carrying metallic compounds and the rocks with which they come in contact, and (2) by reactions due to the meeting and mingling of the waters from above and the waters from below.

(1) The descending waters carrying metallic material dissolved in the upper part of the veins may be precipitated by material contained in the rocks below. This material may be organic matter, ferrous salts, etc. So far as precipitating materials are reducing agents, they are likely to change the sul-

phates to sulphides and precipitate the metals in that form. While sulphides may thus be precipitated either above or below the level of groundwater, they are more likely to be thrown down below the level of groundwater. Other compounds than reducing agents may precipitate the downward moving salts in other forms than sulphides.

(2) In a trunk-channel, where waters ascending from below meet waters descending from above, there will probably be a considerable belt in which the circulation is slow and irregular, the main current now moving slowly upward and now moving slowly downward, and at all times being disturbed by convectional movements. Doubtless this belt of slow general movement and convectional circulation would reach a lower level at times and places of abundant rainfall than at other times and places, for under such circumstances the descending current would be strong. The ascending currents, being controlled by the meteoric waters falling over wider areas, and subject to longer journeys than the descending currents, would not so quickly feel the effect of abundant rainfall. Later, the ascending currents might feel the effect of the abundant rainfall and carry the belt of upward movement to a higher level than normal. However, where the circulation is a very deep one, little variations in ascending currents result from irregularities of rainfall.

In the belt of meeting ascending and descending waters (see Fig 6), convectional mixing of the solutions due to difference in temperature would be an important phenomenon. The waters from above are cool and dense, while those from below are warm and less dense. The waters from above in the neutral zone of circulation would thus tend to sink downward, while waters from below would tend to rise, and thus the waters would be mingled. Still further, even if the water were supposed to be stagnant at the neutral belt, it is probable that by diffusion the materials contributed by the descending waters would be mingled with the materials contributed by the ascending waters.

Ascending and descending solutions are sure to have widely different compositions, and an accelerated precipitation of metalliferous ores is a certain result. As a specific case in which precipitation is likely to occur, we may recall that waters ascending from below contain practically no free oxygen and are

often somewhat alkaline, while waters descending from above are usually rich in oxygen and frequently contain acids, as at Sulphur Bank, described by Le Conte * The mingling of such waters as these is almost sure to result in precipitation of some kind. Le Conte further suggests† that, by the mingling of the waters from below with those from above, the temperature of the ascending column will be rapidly lessened, and this also may result in precipitation, but the dilution would work in the reverse direction

The metals precipitated by the mingling of waters may be contributed by the descending waters, by the ascending waters, or partly by each In so far as more than an average amount of metallic material is precipitated from the ascending waters, this would result in the relatively greater richness of the upper part of veins independently of the material carried down from above.

The above methods of precipitation and enrichment of the upper parts of deposits follow from the reactions of downward moving waters Their effect may be to precipitate the metals of the ascending water to some extent and thus assist in the first concentration. But the results of these processes cannot be discriminated from the second concentration resulting from an actual downward transportation of the material of the first concentration. *It is believed that the downward transportation of metals is the most important of the causes explaining the character of the upper portions of lodes* (see pp. 100–102); *but whether this be so or not, their peculiar characters are certainly due to the effect of descending waters.*

SECOND CONCENTRATION FAVORED BY LARGE OPENINGS OF THE BELT OF WEATHERING.

The concentration of large ore-bodies in the belt of weathering is greatly favored by the abundance and size of the openings as compared with the openings existing at greater depths.

The openness of the rocks above the level of groundwater and the comparative lack of openings below the level of groundwater have already been alluded to as general phenomena, and

* Compare Le Conte, *Am. Journ. Sci.*, 111, vol. xxvi, p. 9

† Le Conte, *op. cit.*, p. 12

an explanation offered for their existence, viz., that in the belt of weathering, solution is the law, and in the belt of cementation, deposition is the law. (See pp. 72-74.) Of course, it is understood that there is usually not a sudden change in the amount of opening space, but that the extremely open upper ground grades into the much less open lower ground at and below the level of groundwater. In some instances the gradation requires some distance. This openness of the belt of weathering and the comparative closeness of the belt of cementation is well illustrated by many limestone regions, for instance, the lead and zinc district of southwestern Wisconsin, already described, pp. 103-109, 142-150. It is also well illustrated by the Leadville district of Colorado, where, Emmons says, "There is a noticeable absence, in the region of greatest ore-development, of channels extending downward."* Thus, so far as the openings are concerned, the conditions for the formation of large ore-deposits are more favorable above the level of groundwater, and as far below the level of groundwater as openings are numerous, than at deeper levels.

The existence of numerous and large openings below the level of groundwater may be explained in individual cases in a number of ways. Of course, the more recent the earth-movements, the more numerous and larger are the openings. In some places the descending waters are not saturated when they reach the level of groundwater, and solution continues for some distance below that level. Furthermore, the level of groundwater varies under different circumstances. Where a region is being uplifted, the level of groundwater, other things being equal, will be descending. Where a region is subsiding, the level of groundwater will be rising. As a result of physiographic changes, there may be alternate valley filling and valley erosion. These changes affect the level of groundwater. In Pleistocene time there was an extensive period of valley filling instead of erosion. Consequent on this, the level of drainage, and therefore the level of groundwater, rose. Also there may be very considerable variations of the level of groundwater, as a consequence of long-con-

* "The Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, 1886, p. 573

tinued climatic changes; such, for instance, as the alternating periods of humidity and aridity in the Cordilleras of the West in connection with the Pleistocene.* The annual variations in rainfall cause a less-marked change in the position of the level of groundwater. All these changes favor alternate solution and deposition; solution when the water falls, precipitation when it rises. Where the underground water has been at a low level, this will be favorable to the production of large openings. Where, later, for some reason, the level of groundwater rises, these openings are in a very favorable condition to be filled with ore, as a result of the reactions of the descending solutions on the ores below and of the mingling of ascending and descending waters.

It might be argued that the existence of ore-deposits in the large openings near the surface is evidence that the ores were not first deposited by ascending waters. However, as has been already explained, in the large openings there may be concentrated mineral material originally distributed by ascending waters through a much greater vertical distance. Thus, a very rich ore-deposit, formed by the reaction of descending waters upon a first concentration produced by ascending waters, might be bounded below by a horizon in which the ground is very close, the comparatively small openings which once existed having been cemented by the material deposited during the first concentration by the ascending water.

DEPTH OF THE EFFECT OF DESCENDING WATERS.

For the depth to which downward-percolating waters produce an effect there can be no doubt of their importance in the production of ore-deposits. The only question which remains open is the depth to which this process is effective. This varies greatly in different districts, and in different mines of the same district. In general, the effect is likely to be deep-seated in proportion as the lode worked is on high ground (see pp. 161-162). Also, in arid regions the level of groundwater is deeper below the surface than in humid regions. Moreover, the process of denudation is slower, so that the downward-moving wa-

* "Lake Bonneville," by G. K. Gilbert, *Mon. U S Geol Surv.*, No. 1, 1890 "Geological History of Lake Lahontan, a Quaternary Lake of South-western Nevada," by L. C. Russell, *Mon. U. S. Geol. Surv.*, No. 11, 1885

ters have both a wider zone in which to work above the level of groundwater and a longer time in which to work upon a given horizon, and thus in such regions the oxides and carbonates are likely to occupy a considerable zone. This is very well illustrated by the copper-mines of Arizona and New Mexico, and by the colorados of the silver-gold deposits in various arid regions. In humid regions, upon the other hand, the level of groundwater is likely to be near the surface. If this be combined with marked relief so that denudation is rapid, the processes of oxidation and carbonation may not be nearly so complete above the level of groundwater. Indeed, in many cases erosion may be so rapid that the sulphurets do not have time for oxidation, and they may extend nearly or quite to the surface, although in such cases they are likely to be enriched, as explained (pp. 99-102), and it is very uncommon to find a deposit in which no effect of descending waters can be discovered.

It has already been seen that the level of groundwater may vary from the surface to 300 meters or more below the surface. Hence it is certain that, from the surface to 300 meters below the surface, the underground waters may be a potent factor in the production of the rich ore-deposits. The deposits in this belt are particularly profitable, not only because of the accessibility of the material, but because of the fact that there is no expense for pumping; and furthermore, the products are in forms which in most cases are easily reducible. This may be illustrated by the gold and silver deposits. In the former, the native gold is free from its entanglement of sulphurets and tellurides; in the latter the silver is largely in the form of the readily extracted chloride, or in some instances as native silver.

Up to this point there will be no disagreement on the part of any one. But the question now arises as to the depths below the level of groundwater to which descending waters produce their effects. This is a question to be answered not by deduction, but by observation. Even Posepny, who emphasizes the effect of ascending waters, agrees that oxidized products are the evidence of the work of vadose circulation, or the circulation of lateral and downward-moving waters.* Furthermore, Posepny

* "Genesis of Ore-Deposits," by F. Posepny (Discussion), *Trans.*, xxiv, 1895, p. 966.

agrees that the iron-mines of the Lake Superior region, which are oxidized products, have been produced by downward-moving waters. A number of these mines have been worked to a depth of 500 or more meters below the level of groundwater. It is, therefore, perfectly clear in these cases that the downward-percolating waters produce an oxidizing effect to a depth of at least 500 meters below the level of groundwater. And this is so in a region in which the level of groundwater is relatively near the land surface, and which is not mountainous. In various other regions oxidized products are also found to a very considerable depth below the level of the groundwater.

In the San Juan district of Colorado, in the Gold King mine, at a vertical depth of more than 300 meters, "the ore taken out is characterized by decomposition, being stained with iron oxide, and showing almost no metallic sulphides."* The author does not state how far this is below the level of groundwater, but merely says that the water-level is deep. Many other veins contain sulphurets, which extend nearly to the surface. In the Cripple Creek district of Colorado and the Judith mountains of Montana—humid areas—oxidized products are found to a depth of 125 meters. The workings at the time when Penrose, Weed and Pirsson† examined the districts had not extended beyond this depth; and therefore we have no knowledge as to the depth at which the last of the oxidized products will be found, or as to the depth to which the sulphides and tellurides have been reacted upon and enriched by the downward-moving solutions from above. This belt of enriched material may be of even greater depth than that of the oxidized products.

As has already been shown (pp 101–116), where the ores are predominantly lean sulphides in the lower workings of the mines, these react upon the downward-moving oxidized salts of the valuable metals, and thus produce rich sulphurets. It is, therefore, clear that descending waters produce enrichment below the level at which oxidized products are found.

* "Preliminary Report on the Mining Industries of the Telluride Quadrangle, Colorado," by C W Purington, *18th Ann. Rept. U S Geol Surv*, pt 111, 1896–97, pp 825–826

† "Mining Geology of the Cripple Creek District," by R A F Penrose, Jr, *16th Ann. Rept U. S Geol Surv*, pt 11, 1894–95, p. 129 "Geology and Mineral Resources of the Judith Mountains of Montana," by W H Weed and L V Pirsson, *18th Ann. Rept U. S Geol. Surv*, pt 111, 1896–97, p 592

Our conclusion is, *that we have positive evidence that the belt in which descending waters are effective in producing rich secondary concentrates, as explained on pp. 99-103, extends to very considerable depths.*

ILLUSTRATIONS OF SECONDARY ENRICHMENT AND DIMINUTION OF RICHNESS WITH DEPTH.

The processes have now been explained by means of which a rich upper belt may be produced. If the argument be correct, it is an inference from this that ore-deposits which have undergone a second concentration are likely to diminish in richness with depth, provided a considerable belt be considered. It remains to give instances, the facts of which confirm the actuality of the processes explained, and illustrate diminution of richness with depth.

At Ducktown, Tenn., at the level of groundwater a belt of rich black copper (copper-glance) appears, which varies from less than one to about two and one-half meters in thickness. Above this belt is gossan very poor in copper, below it is a very low grade cupriferous pyrrhotite.* In this instance it can hardly be doubted that originally the lean cupriferous pyrrhotite extended not only to the present surface, but probably much higher than this. The downward moving waters have transported copper to its present locus near the level of groundwater. Here the copper salts have reacted upon the iron sulphide and produced rich sulphurets.

A case which has been, perhaps, more closely studied than that of any other in the United States is that of the deposits of Butte, Montana. Here Douglas states that rich oxysulphurets are found near the surface. These rich oxysulphurets occur in greatest depths and richness on the summit of the hill, "where it seems as if the copper, leached out of the 400 feet of depleted vein, had been concentrated in the underlying ore, and had thus produced a zone of secondary ore about 200 deep, which contains, as might be expected, about thrice its normal copper-contents."†

* "The Persistence of Ores in Lodes in Depth," by W P Blake *Eng and Min Jour.*, vol. lv, 1893, p. 3. Also, "The Ducktown Ore-deposits and the Treatment of the Ducktown Copper-ore," by C Henrich, *Trans*, xxv, 1896, 206-209.

† "The Copper Resources of the United States," by Jas Douglas, *Trans*, xix, 1891, p. 693.

Emmons says of the Butte deposits *

"Secondary deposition, or transposition of already deposited minerals, has played an unusually important role. In the case of the copper veins it has not been confined to the oxidizing action of surface waters, which has resulted in an impoverishment of the ore-bodies, but below the zone of oxidation it has resulted in the formation of the richer copper minerals bornite, chalcocite and covellite, in part at least by the breaking up of the original chalcopyrite. Unusual enrichment of the middle depths of the lodes has thus been caused. Whether the two processes of impoverishment and enrichment have been differing phases of the action of descending waters, or whether the latter may have been a later result of the rhyolite intrusion, has not yet been definitely decided. It is, however, fairly well determined that the enrichment of the copper deposits is so closely associated with the secondary faulting that it may be considered to be a genetic result of it."

Brown states of the same area that oxidized products extend to the level of groundwater. These oxidized products, according to Brown, promptly change at water level to normal sulphurets. "There follows below a region of varying height, of valuable rock, which again slowly deteriorates in depth; this deterioration, however, being so retarded finally as to be scarcely appreciable"†. He further says that above the level of groundwater is gossan "carrying high values in silver, and particularly in gold."‡. Thus at Butte we have in the belt above the level of groundwater enrichment in silver and gold and depletion in copper as compared with the material below the level of groundwater; and at and below the level of groundwater we have rich sulphides of copper which grade into leaner sulphurets. In the case of the Butte deposits it can hardly be doubted that the comparatively lean sulphides in the deeper workings represent the product of a first concentration, and that the modifications of this material found above and below the level of groundwater represent the work of downward moving waters. To account for the high values of gold and silver above the level of groundwater, one must suppose that this belt has received contributions of these metals from the upward extension of the veins which have now been removed by erosion. The great richness of the copper below the level of groundwater Douglas clearly attributes to the downward

* "Economic Geology of the Butte District," by S. F. Emmons, *Geol. Atlas of the U. S.*, Butte special folio, Montana, 1897.

† "The Ore-deposits of Butte City," by R. G. Brown, *Trans.*, xxiv, 1895, p. 556.

‡ Brown, *loc. cit.*, p. 555.

transportation of the material from the depleted copper veins. However, a part of this material was doubtless derived from an upward extension of these veins precisely as in the case of the gold and silver. For my own part I have little doubt that the precipitation of the rich sulphides was produced by reaction upon the lean sulphurets, as given in the equations pp. 101, 111-112. Indeed, these equations were written out with reference to the facts of the Butte deposits.

Penrose cites the Arizona copper deposits as instances of secondary concentration. These deposits he regards as produced by leaching of the copper from a lean copper-bearing pyrite, and its segregation at the places where the rich ores occur. In this process Penrose, however, says that the volume of the deposit must be decreased; but he makes the point that the smaller amount of the rich product is more valuable than a larger lean deposit, because more easily mined and more readily reduced.*

This process of concentration is further described by Douglas, who notes, also, that the changes have resulted in the production of enriched sulphides from very lean sulphides in the Copper Queen mine. Here, according to Douglas, a large very low-grade copper-bearing pyrite deposit running from the 200- to the 400-foot level contains rich oxysulphides and black sulphides on the outside, and in the interior is mainly lean pyrite.†

The original material in the Arizona locality is as plainly a lean cupriferous pyrites as in Tennessee. Here, however, on account of the peculiar climatic conditions the alterations have not extended to a uniform depth. Instead of the rich belt being a sheet which diminishes in richness below, it occurs in a zone about the entire residual cupriferous pyrites masses. The principles of concentration are, however, identical, and the rich sulphurets are unquestionably due to reactions between the oxidized salts and the lean sulphides. The rich oxidized products of this area, doubtless, were produced directly from the enriched sulphurets. Therefore, in the formation of the rich oxidized

* "The Superficial Alteration of Ore-deposits," by R. A. F. Penrose, *Jour. of Geol.*, vol. 11, 1894, pp. 303-308.

† "The Copper Queen Mine, Arizona," by Jas. Douglas, *Trans.*, xxix, 1900, p. 532.

products there were two stages of alteration; first, the production of rich sulphurets by the reaction of oxidized products upon the lean pyritiferous material, and after that oxidation of the rich sulphurets, which occur partly *in situ*, has also, doubtless, taken place with more or less of transfer of material from one place to another.

An excellent illustration of an enriched upper belt in the case of gold is furnished by the gold-quartz veins of Grass Valley, California, where, according to Lindgren, the decomposed belt of weathering about 50 meters deep contains "from \$80 to \$300 per ton, while the average tenor in depth is from \$20 to \$30."* Furthermore, the rich 50 meters, which contains from four to ten times as much gold as the sulphurets below the level of groundwater, is depleted in silver. However, in some veins the sulphurets extend almost to the surface. Lindgren further states that the sulphurets below the level of groundwater continue with undiminished richness to a depth of 500 or more meters.† He adds that the California region is one in which denudation has extended to a depth of 500 to 1500 or more meters.‡ From these facts it is highly probable, as suggested by Lindgren, that the sulphurets similar to those below the level of groundwater were deposited above the present surface of the country. If this were the case the only possible explanation of the belt of weathering rich in gold and depleted in silver is that descending waters have abstracted a large part of the gold from the 500 to 1500 meters removed by erosion, and have deposited it in the belt of weathering. Its precipitation there was, doubtless, mainly due to the reaction of the oxidized products upon the sulphides, producing sulphurets richer in gold. Later, these rich sulphurets have been oxidized, leaving the enriched belt of free gold. The silver apparently has been transported downward to a greater extent in this belt. One would expect that correlative with the belt above the level of groundwater poor in silver, there would be a belt at and below the level of groundwater richer in silver than that above. Upon this point Lindgren does not give us information.

* "The Gold-quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann. Rept. U. S. Geo. Surv.*, 1895-96, pt. 11, p. 128, 1896.

† Lindgren, *loc. cit.*, p. 163.

‡ Lindgren, *loc. cit.*, p. 183.

Another very interesting case of the richness of the belt of weathering in gold, as compared with the unaltered sulphides below, is furnished by the Australian gold-fields, where the belt above the level of groundwater is several times as rich as the unaltered tellurides and sulphides below, some mining men say ounces above to pennyweights below.*

This rich belt is from 50 to 400 feet. In a portion of the mines of some districts—for example, the Kalgoorlie district—when the bottom of the oxidized zone is reached, the ores are so lean as to be valueless, so that mines which were profitable in the weathered zone were not profitable below that zone † Many of the mines of that district, however, are profitable below the weathered zone. If it had not been for the secondary enrichment of denudation and downward transportation of material, many of the mines would not have been exploited, although Hoover thinks, that in this strange country, the downward concentration is more mechanical than chemical. Thus the secondary concentration by descension is no less an important part of the genesis of the gold-ores of Australia than the first concentration by ascending waters

The lead- and zinc-deposits of the Mississippi valley (see pp. 102-109), are believed to be clear cases of the importance of the action of descending waters. This has already been shown for Wisconsin In the lead and zinc districts of Missouri the galena is at a high horizon, and the sphalerite at a low horizon, precisely as in Wisconsin. Moreover, the arrangement of the different kinds of materials in the veins is very similar to that in Wisconsin, the order of deposition of the minerals from above down being (1) blende, (2) galena, (3) pyrite. This corresponds to the order of the more important deposits in Wisconsin, except that before the blende, marcasite formed. (See p. 104) Lead-bearing ores in Missouri occur in the Cambrian limestones; zinc-ores occur in the sub-Carboniferous limestones, and lead- and zinc-ores occur in the Lower Silurian rocks.‡

* "The Genesis of Certain Auriferous Lodes," by J. R. Don, *Trans*, xxvii 1898, p 596

† "The Alteration of Western Australian Ore-deposits," by H C Hoover, *Trans*, xxviii, 1899, pp 762-764

‡ "The Lead and Zinc Deposits of the Mississippi Valley," by W. P. Jenney, *Trans*, xxii, 1894, pp. 187-188, 197, 199-200

In Wisconsin the ores occur mainly "in the Galena, Trenton, and, subordinately, Lower Magnesian limestones."* However, in all of these districts the ores which have been taken out are very largely above the 50 meter level. The probable explanation of these relations is as follows. The ores were disseminated in various sedimentary strata, and possibly, also, to some extent in the pre-sedimentary rocks. They were concentrated through a comparatively wide vertical range by ascending waters. But the position of the rich ores near the surface is due to secondary concentration by descending waters, concentration going on *pari-passu* with erosion in such a manner that the rich ores are continuously deposited above and below the level of groundwater, as explained in the previous pages. As denudation passes downward, and thus the level of groundwater descends, the horizon of rich concentrates also descends.

The Leadville deposits furnish an instance of the decrease of the richness in silver with depth. Emmons says "There is a fair foundation for the generalization that in the deposits, as developed at the time of this investigation, the ores were growing poorer in silver as exploration extended farther from the surface."†

Another case of the diminution of richness of sulphurets with depth is furnished by the nickel mine of Lancaster Gap, which, however, were not worked beyond a depth of about 75 meters, presumably because "the ores decreased in richness as depth was attained."‡

In addition to these specific instances of the production of a rich upper belt, some general statements have been made which need to be referred to. One of these is made by Douglas in reference to sulphuret mines as a whole. Says he, in the conclusion of his discussion as to the copper resources of the United States, with reference to the various Appalachian deposits, "Like all sulphuret mines, they became poorer as depth was attained"§

* "Geology of Wisconsin," vol. 1v, p. 451

† "The Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, 1886, pp. 554-555

‡ "The Nickel Mine at Lancaster Gap, Pennsylvania," by J. F. Kemp, *Trans.* xxiv, 1895, pp. 626, 884

§ "The Copper Resources of the United States," by Jas. Douglas, *Trans.*, xix, 1891, p. 694

Penrose,* in 1894, discussed the superficial alteration of ore-deposits. He says:

"As a result of these various changes, certain materials are sometimes leached from the upper parts of ore-deposits, which have become porous by alteration, and carried down to the less pervious unaltered parts. Here they are precipitated by meeting other solutions or in other ways, and hence the richest bodies of ore in a deposit often occur between the overlying altered part and the underlying unaltered part. This is not always the case, but it is true of some copper, silver, iron and other deposits"†

De Launay,‡ in 1897, emphasizes the frequent occurrence of rich products near the surface, which in some cases are oxidized products, and in others are sulphides. He, however, explains the richness of the deposits by the abstraction of more soluble material. This frequently results in transforming a low grade product into a rich ore. By this process a poor sulphide may be changed to a rich sulphide, as, for instance, cupriferous pyrites or chalcopyrite may be transformed to covellite or chalcocite by abstraction of iron sulphide. It is a natural deduction from De Launay's§ explanation, that the volume of the material is decreased, although he does not make this point.

De Launay further emphasized the point that the ore-material of veins may have been repeatedly transferred from one place to another, and suggests that a part of the material now found in veins may have been transferred from vein material which was once above the present surface of denudation.

While it is believed to be a very general case, if a long enough scale be used, that ore-deposits diminish in richness with depth, it is well-known that above the level of groundwater the valuable materials may be almost wholly dissolved and deposited at or below the level of groundwater by the reactions above stated, as at Ducktown, Tennessee, or partly dissolved and transported below, as at Butte, Montana. Thus, for a certain depth the ores may increase in richness. This exception, however, does not affect the common rule as to diminution of richness with increasing depth.

* "The Superficial Alteration of Ore-deposits," by R. A. F. Penrose, Jr., *Jour. of Geol.*, vol. 11, 1894, pp. 288-317.

† Penrose, *cit.*, p. 294.

‡ "Contribution à l'Etude des Gîtes Métallifères," by M. L. De Launay, *Annales des Mines*, 9th ser., vol. xii, 1897, pp. 151-152.

§ De Launay, *cit.*, p. 194.

GENERAL.

It is apparent from the foregoing that there has been a general understanding that a rich upper belt has been produced in many ore-deposits. Le Conte,* who appreciated this, suggests that the rich belt may be explained by supposing that precipitation by ascending waters does not occur at great depth, because the solutions do not get saturated until comparatively near the level of underground water. However, it is to be remembered that the upper part of a fissure is that receiving abundant lateral waters which have taken a comparatively brief journey under conditions of low pressure and temperature; whereas the solutions lower down have taken a longer journey under conditions of high pressure and temperature. In this connection it might be further supposed that the varying richness could be partly explained by the lessening temperature and pressure of the rising solutions. But if this be true, one would expect the most insoluble constituent to be precipitated deepest down. In the case of the lead-zinc-iron deposits this would make the galena most abundant at depth, the sphalerite most abundant at a higher level, and the iron sulphide the dominating constituent at the highest levels. In the case of the copper-iron deposits, the rich sulphides of copper would be in the lower levels and the cupriferous pyrites at the higher levels.

As already seen, Penrose's explanation of the phenomenon of a rich upper belt is that the concentrates have been produced by downward transportation and precipitation by meeting other solutions. De Launay's explanation of the phenomena is enrichment by the abstraction of the more soluble and less valuable material, thus producing a smaller quantity of relatively rich product.

While the reactions between the oxidized products and the sulphides are emphasized, and are believed to be the most fundamental and widespread, my own explanation† is, mainly,

* Le Conte, *loc. cit.*, p. 12

† Just as I am sending this paper to the press in its revised form (a preliminary proof edition was published and distributed in February, 1900), I am in receipt of a paper upon the "Enrichment of Mineral Veins by Later Metallic Sulphides," by Walter Harvey Weed (*Bull. Geol. Soc. Am.*, vol. xi, pp. 179-206).

that oxidized soluble products are produced in the belt of weathering; that these *in situ* or lower down react upon the lean sulphides. In this way a belt of rich sulphurets is formed. Later, in consequence of denudation, these rich sulphides pass into the belt of weathering. Here they are again exposed to the oxidizing forces, where *in situ* they are largely transformed to oxides, carbonates, etc., and a belt of rich oxidized products above the groundwater is formed. However, in part, when oxidized, they are taken into solution, again transported downward, and again react upon the sulphurets. In arid regions where the amount of downward-moving water is small, the oxidized products formed from the rich sulphurets are likely to remain in large part *in situ*. Where, upon the other hand, water is abundant the sulphides when oxidized are in large measure likely to be carried downward, and again react upon the sulphides below and further broaden and enrich the belt of sulphides. Thus, under different climatic conditions, we may

This paper strongly emphasizes the enrichment of an upper belt through the action of descending waters. Moreover, the paper includes the reactions of the oxidized products upon the poor sulphurets, thus producing rich sulphurets. Many occurrences are given which illustrate the enrichment of sulphides by descending waters, including copper, silver and zinc deposits. Some of the illustrations given by Mr. Weed I also have used. Others are additional to those given by me. In general it may be said that Mr. Weed's paper and that part of my own which deals with secondary enrichment by descending waters are supplemental and support each other, since each did his work and arrived at his conclusions in entire ignorance of the fact that the other was working along a similar line.

Upon one point only is there difference of opinion between us. Mr. Weed, in his general statement, says that the part of the veins "below the permanent groundwater level consists of the unaltered sulphides which compose the original ore of the vein. This part constitutes the zone of primary sulphide ore" (p. 181). However, while Weed makes the above general statement, he appears to appreciate that in individual cases rich oxidized sulphides may be produced below the permanent groundwater level, for he says that at Elkhorn, Montana, this level is only 185 to 210 meters below the surface, whereas the sulphides enriched by descending waters extend to the depth of 600 meters (p. 204). If my reasoning be correct, the zone of secondary enrichment by descending waters will ordinarily extend far below the permanent groundwater level, in many instances to the depth of several hundred meters. Indeed, not only the Montana instance, but other illustrations given by Mr. Weed confirm this conclusion. In the pyrite deposits of Spain and Portugal, described by Vogt, the ores decrease in richness to the depth of 350 meters (p. 198). Also in Norway, if I understand Mr. Weed correctly, the diminution of richness of the copper deposits with depth extends from 350 meters to over 700 meters.

have a rich oxidized zone, a rich sulphide zone, or both, in varying proportion.

While the reaction between the oxidized products and the sulphides has been strongly emphasized in this paper because it is believed to be the most fundamental of the causes producing a rich upper belt, it is understood that other factors may also help in this process. As already pointed out, reduction and precipitation of the metals of descending solutions may take place through the agency of organic matter or other reducing materials contained in the rocks, or by meeting ascending solutions carrying precipitating agents, also near the surface more than an average amount of original precipitates from ascending solutions is a possibility in some cases. (See pp 122-123)

Summarizing, it appears to me, therefore, that the existence of a rich upper belt in many deposits, and the frequent diminution of richness of the ores in passing downward from the surface to some distance below the level of groundwater, cannot be explained as the work of ascending waters alone or as the work of descending waters alone; but is fully explained as due to the work of ascending and descending waters combined. Ascending waters produce a first concentration. A second concentration by descending waters produces the rich products. Moreover, these rich products are found in the few meters or few hundred meters of the outer crust of the earth. When it is remembered that the greater part of the ores which have yet to be abstracted from the earth will come from the first 500 or 700 meters, and when it is further considered that the effect of descending waters may be felt to these depths, it becomes evident that the process of second concentration by descending waters is a very important one indeed, so far as the economic value of ore-deposits is concerned. Indeed, as a result of it there is concentrated in the extreme outer shell of the crust of the earth a large portion of the products which during the first concentration may in many cases have been distributed over 1500 or 3000 meters or more, but which have now been largely removed by erosion. We therefore conclude that, for a large class of ore-deposits, *a second concentration by descending waters cannot be said to be one what less important in the genesis of ores than a first concentration by ascending waters.*

It follows from the foregoing that one of the most important classes of ore-deposits is that produced by the joint action of ascending and descending waters.

THE PRECIPITATION OF ORES BY DESCENDING WATERS ALONE

For the sake of simplicity and continuity of exposition, the effects produced by descending waters have been applied to deposits which have been first concentrated by ascending waters. However, it is perfectly clear that a concentration by descending waters alone may be adequate to produce ore-deposits. Indeed, this is definitely known to be true of some of the most important ore-deposits, as for instance many of the iron-ores. A conspicuous case is that of the Lake Superior iron-ores, which very well illustrate the process of formation of ores of this class. Since the genesis of the Lake Superior iron-ores is fully discussed by me in the Twenty-first Annual Report of the U. S. Geological Survey, this class of ores is not further discussed here.

SPECIAL FACTORS AFFECTING THE CONCENTRATION OF ORES.

In Part I it has been shown that the underground circulation may be effective to the bottom of the zone of fracture, and in Part II it has been seen that the concentration of ores is an orderly but complex process. However, the discussion has not taken into account a number of the special factors which affect the concentration of ores. The general discussion may need great modification to adapt it to a particular district. To illustrate my meaning, it may be well to consider some of the additional factors affecting the deposition of ores, and to point out the more obvious possible modifications of the general theory which may result from them. The effect of (1) variations in porosity and structure, (2) the character of the topography, and (3) physical revolutions, will be briefly considered.

Variations in Porosity and Structure.

There are many ways in which variations in porosity and structure may affect the concentration of ores by influencing the circulation of waters.* The different strata of the sediment-

* Compare Emmons's "Structural Relations of Ore-Deposits," *Trans.*, xvi, 1888, 804-839

ary rocks vary greatly in porosity. The igneous rocks, and especially the lavas, also vary much in porosity. The metamorphosed equivalents of either sedimentary or igneous rocks may differ in porosity. The contact of rocks frequently furnishes trunk-channels for underground circulation. Bedding partings produced by shearing stresses during deformation furnish sheet channels parallel to the strata, or openings on the anticlines or synclines. Some strata when deformed may yield by fracture, furnishing channels for water-circulation, while interlaminated strata may yield by flowage, thus remaining relatively impervious. These various irregularities may combine in different ways.

All irregularities in porosity and structure may modify, and in many cases profoundly, the simple general statements of the present paper (pp. 54-62, 79-84) concerning the character of underground circulation and the concentration of ore-deposits. At some future time it may be possible to divide the modifications of the general circulation due to variation of porosity and structure into classes, but for the present this cannot be done. The modifications of the general circulation which occur in many individual districts must first be studied and described, after which generalizations may possibly be made. However, some general statements may be made in reference to certain modifications of the general underground circulation.

The Complexity of Openings.—In the general discussion an ore-deposit has been spoken of as if it were a single continuous mass formed in a large opening. It is clear this is not the fact, but, on the contrary, that many ore-deposits have very complex forms. An ore-deposit in a single large opening is exceptional. From large single openings to openings of an extraordinarily complex character, there are all gradations. A trunk-channel of circulation may be a set of distributive faults; it may be a group of parallel or intersecting sets of openings along joints, it may be the minute parallel openings of fissility; it may be a group of openings along bedding planes; it may be the shrinkage openings formed within or along the borders of cooling magma, it may be the openings in an autoclastic rock or reibungs-breccia along a fissure, it may be the multitude of openings of a sandstone or a conglomerate.

Consequent upon the many irregularities, trunk-channels of

circulation may vary from vertical to nearly horizontal attitudes. But ore-deposits ordinarily have important vertical components, although they may be found in nearly horizontal positions. In such cases the trunk-channels forming the deposits had probably vertical components somewhere else.

It is hardly necessary to give illustrations of ore-deposits for each of these complex conditions. However, as very excellent illustrations of veins of a very composite character may be mentioned the Cripple Creek deposits* and the gold-quartz veins of Nevada City and Grass Valley, California†. The essential point, so far as the discussion of the foregoing pages is concerned, is that ore-deposits commonly occur at places where there are trunk-channels for ascending or descending waters, or both. In order that metalliferous material shall be brought to a place and deposited in large quantity, there must be long-continued circulation. It matters not whether a trunk-channel is a single passage or is composed of an indefinite number of minor passages, the principles given on the previous pages are applicable to the deposition of ores in such trunk-channels.

In various regions the conditions are so exceedingly complex that ore-deposits close together may differ from one another greatly. This is the best evidence that, notwithstanding their contiguity, the underground trees of water circulation have been, if not independent, at least partly so.

This is well illustrated by the ore-deposits of Butte, Montana. Here, apparently, the metallic contents of the individual feeding streams and even the trunk-channels are very different within short distances. At this place are two main zones of mineralization. The more important product of one of these mineral zones is silver sulphide, which is associated with sulphides of lead, zinc and iron, and with silicate of manganese. The chief product of the other mineral zone is copper, but this copper carries silver in important amounts.‡

* "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., *16th Ann. Rept. U. S. Geol. Surv.*, pt. ii, 1894-95.

† "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann. Rept. U. S. Geol. Surv.*, pt. ii, 1895-96, pp. 158-160, 259.

‡ "Notes on the Geology of Butte, Montana," by S. P. Emmons, *Trans.*, xvi., 54, 1888.

Impervious Strata at Various Depths.—Slichter's theoretical investigations on the motions of groundwaters show that, in order to discuss the flowage under any given set of conditions, it must be assumed that the flowage is limited only by an impervious stratum * It is, of course, understood that there is no such thing in nature as an absolutely impervious stratum, but there are many strata which are practically impervious. Wherever there is an impervious stratum in a district, this must be counted as the limit of circulation in that direction. The impervious stratum may be a plastic shale which yields to deformation without fracture, it may be a rock intruded after deformation has occurred, thus making a barrier. If an impervious stratum exists at a given depth, the effective underground circulation for that district is there limited or divided, whether the stratum be at the depth of 100 or 1000 or more meters. Of course there will be all gradations, from practically impervious strata to strata which merely check the circulation. It is believed that in the average case the limit of effective circulation is probably much less than the theoretical limit of 10,000 meters given by the depth of the zone of fracture.

However, if an impervious stratum be but 100 meters from the surface and fissures be limited to that depth or interrupted, the laws given pp. 54-62 will commonly apply to the circulation above the stratum. Therefore such a fissure may be occupied by ascending water in the lower part and by descending water in its upper part. Hence an ore-deposit contained in such a shallow fissure may be the result of a single concentration by ascending or descending waters, or of two concentrations, the first by ascending and the second by descending waters.

The foregoing statement in reference to the practical limits of underground circulation for the ore-deposits of a given district may be true even if below the impervious stratum there are other strata, fed from a distance, in which circulation is occurring.

Such lower pervious strata may have circulations of their own independent of the higher circulations, and this circulation may produce ore-bodies. This is beautifully illustrated by the Enterprise mine of Rico, Colo. (see Fig 9, p 154), described by

* "Theoretical Investigation of the Motion of Ground Waters," by C S Slichter, 19th Ann Rept U. S Geol. Surv for 1897-98, pt. 11, pp. 329-357, 1899

Rickard,* in which the ore is confined to fissured and broken limestones and sandstones below a black shale, which when bent did not fracture, and therefore afforded no channels for water circulation.

In this connection it may be well to mention the Mercur district of Utah (see p. 156), where a silver ledge and a gold ledge about 100 feet apart each occur in limestone below a shale-like stratum of altered porphyry. Spurr regards the silver ledge as produced by an earlier mineralizing period, and the gold ledge as resulting from a later period of mineralization † It may be suggested that the true explanation of the existence of two mineral ledges so near together and of such different mineral character is that in this district there were two independent circulations separated by impervious strata, the upper one, producing the gold ledge, being between the two impervious porphyry belts, while the lower one, forming the silver-deposit, was below the lower impervious layer.

That a difference of opinion exists as to the source and manner of deposition of the lead and zinc deposits of the upper Mississippi valley has already been mentioned. (See p. 109) I believe that these deposits furnish an instance of two concentrations where an impervious stratum limiting the concentrating circulation was at a very moderate depth.

The succession for this district in descending order, according to Chamberlin, ‡ is as follows ·

Niagara limestone, 137 meters thick.

Cincinnati shale, originally 61 meters thick (in Iowa called the Maquoketa shale) §

Galena limestone, bearing organic matter, 76 meters thick.

Trenton limestone, bearing organic matter, 12-30 meters thick, with mean of 21 meters, having at its top an oil-bearing shale, || "two or three to several feet in thickness at

* "The Enterprise Mine, Rico, Colo.," by T. A. Rickard, *Trans*, xxvi., 1897, 976-977, also Figs. 19, 36, 40

† "Economic Geology of the Mercur Mining District, Utah," by J E Spurr, 16th Ann Rept U S Geol. Survey, pt 11, 1894-5, pp 367-369.

‡ Chamberlin, *op cit*, pp 407-419.

§ "Lead and Zinc Deposits of Iowa," by A G Leonard, *Iowa Geol. Survey*, vol. vi, 1897, p 23

|| Blake, *Bull Geol Soc Am*, vol v., pp 28-29, also *Trans Am Inst Min. Eng*, vol xxii, pp 629-632.

points,"* and containing throughout its mass various shaly layers, which, however, are "quite decidedly most prevalent near the base of the formation."†

St. Peter's sandstone, 15-46 meters thick.

Lower Magnesian limestone, 30-76 meters thick.

Potsdam sandstone, 213-244 meters thick.

Pre-Cambrian.

It is to be noted that the Galena limestone is bounded by impervious shales above and below, and that the same statement applies to a less extent in reference to the Trenton limestone. As to the impervious character of the thick Cincinnati shale above the Galena, there is no doubt. One might, however, question the impervious character of the thin bed of shale at the top of the Trenton, but that this is relatively impervious is strongly indicated by the fact that in the Shullsburg and other districts, as pointed out by Blake, the ore-deposits stop at the top of this layer.‡ While in the Trenton the impervious shales are more prominent at the top and near the bottom, there are more or less impervious layers within the Trenton.

The strata dip to the southwest. Chamberlin says for Wisconsin, "The strata on the north side of the lead region are 500 feet (152 meters) higher than those of the south side, and if traced farther the difference in altitude would be found greater. Beds on the eastern side are 350 feet (107 meters) higher than on the west side."§ Superimposed upon the general southwest monocline of the district are a number of subordinate anticlines and synclines, and the ores are mainly confined to the synclines.|| At the time of this deformation the brittle limestones were probably fractured, producing the present complex system of intersecting joints, but the plastic shales were deformed with comparatively little fracturing. The time at which the deformation occurred is not definitely known, but in all probability it antedated the deep erosion and concentration of ores in the district ¶

* Chamberlin, *cit*, p 412 † Chamberlin, *Geol of Wis*, vol iv, 1882, p 409.

‡ "Lead and Zinc Deposits of the Mississippi Valley," by Wm P Blake, *Trans. Am Inst. Min. Eng*, vol. xxii., 1894, pp. 629-632 (Discussion of Jenney's paper)

§ Chamberlin, *cit*, p 422.

|| Chamberlin, *cit*, pp 432-438

¶ "Lead and Zinc Deposits of the Mississippi Valley," by W P Jenney, *Trans Am Inst Min Eng*, vol xxii, 1894, pp 208-209 Discussion of Jenney's paper, by Wm P Blake, *op cit*, pp 628-629 Chamberlin, *op cit*, pp 427, 485

Areally the ores occur to a much greater extent east of the Mississippi river than west of it, that is, mainly east of the main line of drainage. As to horizons, by far the greater quantity of ores which have yet been abstracted were found in the Galena limestone.* However, considerable quantities of ores have been taken from the Trenton, and subordinate quantities from the St Peters and Lower Magnesian. The ores occur in the Galena from the top to the bottom. In cases where erosion has not cut deep into the Trenton, the ore-deposits are apt to be found near the overlying Cincinnati shale. For instance, in Iowa, where the shales are close at hand as a continuous formation, Leonard† states that the ore occurs "mostly near the top of the Galena limestone, within the upper 50 or 60 feet (15 meters to 18 meters)." Where the drainage lines have cut through the Galena into the Trenton or lower formations, the ores of the Galena are likely, in large measure, to be near the bottom of the formation, and considerable bodies may rest upon the oil-rock which marks the beginning of the Trenton.

Following Chamberlin, I think it probable that a large part of the material of these ores was once disseminated through the sedimentary rocks, and especially the limestones. My conception of the probable process of concentration in the Galena limestone is as follows:

While in the Wisconsin lead district the Niagara limestone and Cincinnati shale are only found on occasional mounds, as pointed out by Chamberlin,‡ there is no question but that these formations once extended over the entire district. As already noted, the Cincinnati shale is a very impervious stratum. Until it was cut through by the drainage, it is probable that effective concentration of the ores did not begin. When it was once cut by erosion, then I conceive the main concentration history of the ore-deposits to have begun. The Mississippi river and areas adjacent were the places where the drainage was the lowest. However, these were not the places first cut through by erosion, for the difference between the level of the Mississippi drainage and the tributaries adjacent is not so

Geol. of Wis., vol. iv., pp. 407, 457, 481.

† Leonard, *cit.*, pp. 43, 61.

‡ Chamberlin, *cit.*, pp. 410-412.

great as the dip of the strata to the southwest. In all probability, therefore, the Cincinnati was first cut through, and the Galena encroached upon by erosion north and east of the lead and zinc district. This is probable from the fact that at the present time the Mississippi river for the most part in the lead district is on the Trenton, and never reaches deeper than the St. Peters; while the majority of the smaller streams in the northeastern part of the lead district have cut into the St. Peters, and the headwaters of some of them, notably the Pecatonica, Platte, the Grant river, have cut through the St. Peters into the Magnesian; while still farther to the northeast, north of the divide, occupied by the Lancaster branch of the C. & N. W. Ry., the strong Wisconsin has cut down to the Cambrian *

It is to be remembered that the pervious strata overlain by impervious strata along the Mississippi river bear water under pressure, as is shown by numerous artesian wells. The feeding area is the higher ground to the northeast. It is highly probable that the broken brittle Galena limestone was a formation which was capable of carrying water to considerable distances, and in considerable quantities, although probably not comparable in these respects to the St. Peters or Potsdam sandstones. The lead and zinc district of Wisconsin is wholly south of the divide between the Wisconsin river and the tributaries of the Mississippi. When the Wisconsin drainage north of the divide had cut through the Cincinnati shale, this furnished a feeding area to the Galena limestone. When later the Mississippi tributaries south of the divide had cut through the Cincinnati shale into the Galena, the waters entering north of the divide escaped.

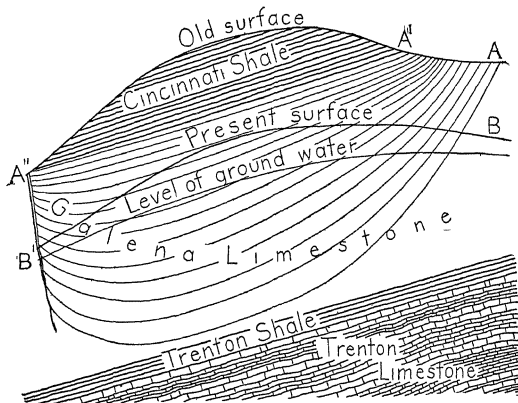
As erosion continued, the area in which the Cincinnati was cut through and the Galena penetrated, gradually extended to the southwest until the Mississippi itself had cut through the Cincinnati. During this time the water entered the Galena limestone at the higher elevations, that is, to the north and east, followed along this formation, and escaped at some lower point toward the Mississippi river. While the water to the greatest extent followed the upper portion of the Galena, it is believed that this broken formation was searched to its deepest

* See "Atlas of Wisconsin," pls 1 and viii.

part according to the laws of flowage given pp. 54-62. The places of escape were near the top of the formation, and, therefore, the waters of the trunk-channels leading to these places were ascending.

As erosion slowly progressed, the zone of rising waters and escape slowly migrated from the northeastern part of the lead and zinc district to the southwestern part. The nature of the circulation at a given time is roughly represented by Fig 7, a northeast-southwest vertical section. The surface of the country

FIG 7.



Ideal Vertical Section of the Flow of Underground Water in the Galena Lime-
stone of the Upper Mississippi Valley

is shown by A, A', A'', in which A, A' is the cross-section of a northwest and southeast belt, where waters enter, and A'' is in a parallel belt to the southwest, in which the waters escape. The numerous curved lines below the Cincinnati shale are intended to represent the circulation. The downward-moving lateral-moving waters, in the early stages of their journey, were oxidizing and dissolving waters. When, through the organic matter contained in the formation, the oxygen had been exhausted and the oxidized products reduced, the waters were sulphuretted

waters, as explained pp 93-95. The upward-moving waters in the trunk-channels (A'' B') were precipitating waters, as explained pp 82-83. And especially the material was likely to be precipitated where the waters came in contact with abundant organic material.

Where the limestone itself contained many carbonaceous substances, the material precipitated might have been widely disseminated, but as the carbonaceous material was more abundant in the clay layers, which, to some extent at least, represented places where clay openings and ore-deposits now exist, the ore material was still more largely precipitated. The transfers of ore material at this time were, indeed, exceedingly complex, but because of a combination of all of the factors considered in the general part of this paper, the material was precipitated to a greater degree in the trunk-channels where the water was ascending than anywhere else.

In an early stage of the process the first concentration by ascending waters took place in the northeastern part of the district. By the time that erosion had cut through the Cincinnati into the Galena in the southwestern part of the district, and ascending waters were concentrating ores, the northeastern part of the district might have been a feeding area where waters were descending, and a second concentration taking place. Therefore, the second concentration by descending waters was going on in the northeastern part of the district at the same time that the first concentration by ascending waters was occurring to the southwest. At the present time the erosion has cut sufficiently deep so that the second concentration by downward-moving waters has extended quite to the Mississippi river, and, indeed, to the west of it. At the present time the condition of affairs, except the circulation, is represented by Fig. 7 below the line B B', which may be taken as the present surface of erosion.

This general statement as to the order of events concerning the district as a whole would also apply to the local anticlines and synclines. Other things being equal, where there were anticlines there erosion would first cut through the Cincinnati shale, and water make its way into the Galena formation. Later, when erosion had cut deep enough to expose the bottoms of the adjacent synclines, there the water entering at the anticlines arose and escaped, and a first concentration occurred in the

synclinal areas. Later, when erosion had cut deeper, a second concentration by descending waters occurred, and thus these concentrations were localized in the synclines, where, according to Chamberlin, they now occur. In this connection it is to be remembered that the anticlines and synclines of the district are very gentle. Therefore, the conditions are here different from those of a district where there are sharp, strongly pitching folds covered by impervious strata. (See pp 150-157)

My conception of the process of concentration of ores in the Galena limestones is, therefore, that of a circulation practically limited above by the Cincinnati shale and largely limited below by the impervious oil shale of the Trenton. To what extent ascending waters from the St. Peters, Cambrian and pre-Cambrian rocks under the pressure of considerable head were able to work up through the more or less impervious shales of the Trenton limestone is uncertain. For the purposes of this paper it makes little difference whether during the time of deposition of ores in the Galena limestones by ascending waters the circulation was practically limited by the Cincinnati shale above and the Trenton below, or whether a contribution of waters ascended from greater depths. For a given point where the Cincinnati shale had just been removed, the first concentration occurred by ascending waters, and later when the Cincinnati shale had been removed farther to the southwest the second concentration by descending waters took place. The belt of second concentrates by descending waters slowly migrated downward as erosion extended into the Galena. Where the denudation has gone a little way into the Galena, the ore-deposits are found near its upper part. Where denudation has gone well down into the Galena, the ore-deposits are found near its lower part. Where the lines of drainage are considerably below the Galena the second concentration and downward migration of the ores has resulted in the formation of considerable deposits directly upon the petroleum oil-rock at the top of the Trenton. In these cases the materials exploited are probably the second concentrates from the entire Galena formation.

The precipitation of the lead- and zinc-ores by reactions of the oxidized products upon the remaining sulphides, and by the reducing action of the organic material contained in the rock and the organic material coming down from above, have already been considered. (See pp. 105-109.) However, in this connec-

tion it should be noted that the position of the ores upon the oil-rock is probably explained through the reducing action of solutions slowly oozing up through the shale, for the ore is not mainly precipitated in the oil-rock, but immediately above it. In this connection it is to be remembered that all of the pervious strata capped by impervious strata in this region bear waters under pressure. Therefore, water would slowly pass up through the shale, for no formation is absolutely impervious.

It will be seen at once that the above theory of circulation explains the formation of rich deposits near the top of the Galena, as in Iowa, and these deposits are very difficult to account for solely upon the theory of descending waters. It accounts equally well for the formation of rich ores in the middle and lower horizons of the Galena where denudation has gone further. It accounts for the much wider distribution of the ores east of the Mississippi river than west of the Mississippi river, since the strata west of the Mississippi river continue to dip to the southwest; and the drainage west of the river has cut only for a little way deep enough so that the process of concentration as above outlined could occur.

In the parts of the Upper Mississippi valley district where erosion has cut deeply into the Trenton, and especially where it has gone into the St. Peters, a similar history is applicable to the Trenton formation; only the Trenton is more variable in its porosity than the Galena, and the deposits may not have been wholly derived from the Trenton formation, but may have received a subordinate contribution from the Galena formation which has been removed by erosion in part or altogether.

In the application of the foregoing it is, of course, understood that the action of ascending and descending waters in a given fissure is not wholly successive; but is in large measure simultaneous. In the early stages of the deposition of an ore-deposit in a given fissure, ascending water would be likely to be the dominant factor; in an intermediate stage both ascending and descending waters would be at work, and in the later stages of the process, and at the present time, descending waters are the dominant, and, perhaps, in the cases of many of the deposits where the oil-rock of the Trenton is near the surface, almost the sole factor.

At the bottoms of valleys the waters have continued to be

essentially ascending instead of descending to the present time. The fact of their present ascension Chamberlin^{*} notes. Thus in these places a second concentration has not occurred, and, therefore, such places are deficient in workable ore-deposits, as noted by Chamberlin.[†] (See p. 163)

The case of the lead and zinc district has been dwelt upon, as it seems to me to illustrate almost ideally the practical limitations of circulating water by impervious strata. It shows that precisely the same principles of ore deposition are applicable when the limit of circulation is less than 100 meters deep that apply when the circulation extends to the very bottom of the zone of fracture.

If my views be compared with those of the ascensionists, typified by Jenney, and the descensionists, typified by Chamberlin, it will be seen that I occupy an intermediate position. Upon the fundamental point as to whether or not the ores are derived from a deep-seated source or are derived from sedimentary rocks, I am inclined to follow Chamberlin, although I do not feel certain that some of the material for the ores were not derived from a deeper source.

The account given pp. 102-109, 142-150, in reference to the ore-deposits of the Upper Mississippi valley is not even approximately complete. To give a satisfactory account of the genesis of the ore-deposits of this district, would require a detailed study and a monographic report. Such a report upon many phases of the problem—a remarkable paper—has already been written by Chamberlin.[‡] When the study is completed, it will be possible to explain not only the general order of mineral succession vertically, but the multifarious and complex distributions, such as the cycles of depositions already mentioned.

Pitching Troughs and Arches.—Another interesting special case of influence of porosity and structure is that where alternately pervious and impervious layers are in a set of pitching folds. The varying porosity may follow from original difference in the porosity of the layers, or it may result from the deformation itself. The more rigid strata may be deformed by fracture, and the less

^{*} Chamberlin, *op cit*, p 565

[†] Chamberlin, *op cit*, p 563

[‡] "Ore-deposits of Southwestern Wisconsin," by T C Chamberlin, *Geol. of Wis*, vol 14, 1882, pp 365-571

rigid by flowage. Also, the convex sides of the brittle layers are likely to be more fractured, and, therefore, more porous than the concave sides. This would place the more porous parts of a stratum in contact with the confining impervious stratum below at the synclines and above at the anticlines. Furthermore, where the strata are closely folded, unless there is very great distortion of the strata, openings will form between the layers at the synclines and anticlines, thus furnishing trunk-channels

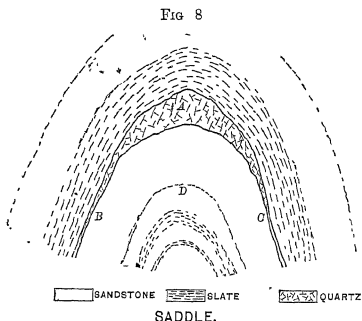
Any combinations of porous layers with impervious layers in folds are likely to give trunk-channels for underground water at the troughs above impervious strata, and at the crests below impervious strata. When descending waters come into contact with an impervious stratum, they are deflected toward the synclines, and there finding the trunk-channels, they follow the troughs downward along the pitch. When ascending waters come into contact with an impervious stratum, they are deflected toward the anticlines, and there finding the trunk-channels, follow the arches upward along the pitch. Therefore, ore-deposits produced by descending waters are often found in pitching troughs underlain by relatively impervious strata; and ore-deposits produced by ascending waters are rather frequently found in pitching arches overlain by impervious strata.

The Lake Superior iron-ores furnish an admirable illustration of the concentration of ores by descending waters in pitching troughs which are on impervious basements. Since these ore-deposits, which fully illustrate the principles of concentration of ores by descending water in pitching impervious troughs, are fully discussed elsewhere, ores of this class will not be here further considered.

A case in which ore is probably deposited by ascending waters in arches, because there concentrated by impervious roofs, is furnished by the Bendigo gold-district of Australia.* The typical position for the gold in the district, according to Rickard, is immediately below a slate, on top of a sandstone. The slate is the impervious stratum and the sandstone the pervious stratum. The ores are, presumably, in part, in the openings between the

* "The Bendigo Gold-Field," by T. A. Rickard, *Trans.*, xx, 1892, pp. 463-545.

layers made by folding * (Fig. 8) Moreover, in this district there are a large number of alternations of pervious and impervious strata, as a result of which a number of concentrations have occurred one above the other While Rickard does not specifically speak of the pitch of the anticlines, the longitudinal sections show that they do have a marked pitch Rickard's explanation of the location of the ores† is that the apices of the anticlines would furnish more open passages than the synclines,



The Concentration of Ore by Ascending Water at a Crest below an Impervious Stratum. After Rickard (*Trans*, xx, 467, Fig 2)

but why at a given level this would be so does not appear. This explanation may possibly be to some extent applicable, but the pitching arches concentrating the ascending solutions below impervious strata are believed to be the main cause of the localization of the gold.

Another excellent illustration of ore-solutions concentrated by an impervious roof is furnished by the Mercur district, Utah, described by Spurr,‡ where two ore-bearing beds, one called the silver ledge and the other called the gold ledge, about 100

* Rickard, *loc. cit*, Fig 2, p 467. See also Fig 12, p 481; Fig 13, p 483, Fig 37, p 499, and Fig. 38, p. 501

† "The Origin of the Gold-Bearing Quartz of the Bendigo Reefs," by T. A. Rickard, *Trans*, xxii, p 319

‡ "Economic Geology of the Mercur Mining District, Utah," by J E Spurr, 16th Ann Rept U S Geol Surv, pt ii, 1894-95, pp 365-7, 395, 399-401, 449, 454, see also Pl xxxiv, Figs 44 and 45, and Pl xxv, p 360.

feet apart, occur in a limestone below seams or beds of shale-like material, which, however, is very much altered porphyry. The ores are especially localized where fissures reach these beds, and thus displace them, and in some cases form local arches, although Spurr does not mention this latter fact. Moreover, the entire ore district is located upon a general anticline, furnishing a general pitching arch.

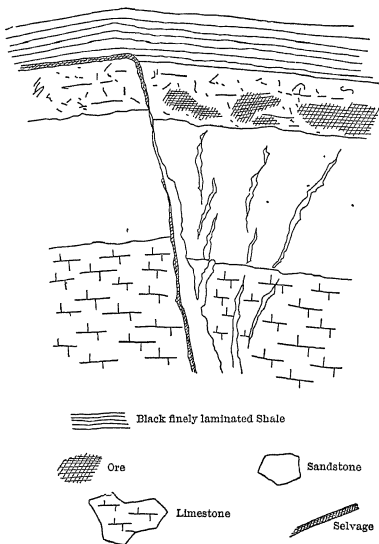
Another exceedingly interesting illustration of the deposition of ores below an impervious stratum in pitching arches is that furnished by the Enterprise mine of Rico, Colorado, described by Rickard in a paper already cited.* In this district above the ore-bodies is an impervious shale which is not broken at all, or very rarely, by the fissures. The ore occurs in two places, (1) in nearly vertical fissures extending indefinitely downward below the shale, but not upward into it. The verticals are cut by cross-fissures, and where the intersections occur the fissures are likely to be unusually rich. (See pp. 85-88) (2) The larger masses of ore are found in crushed or fractured limestone below the black shale and above the fissures. Moreover, these bodies are narrow laterally, and are parallel to the strike of the verticals and also of the cross-veins. Figs. 9 and 10 show that they occur below anticlinal flexures of the shale made by the deformation resulting in the faulting in the more brittle rocks below. Rickard regards the deposits as the result of ascending waters, since the fissures continue downward but do not extend upward into the shale. It is believed that when the Enterprise deposit is further studied it will be found that the flexures of the shale furnishing the anticlinal arches have a pitch (and indeed this is indicated by Fig. 10), and that the waters issuing from the verticals and the cross-fissures followed these arches upward until the pitch somewhere brought them to the surface, at which places the waters escaped as springs; for the waters of the ascending circulation must have somewhere escaped, and that they could not do through the impervious shale.

At this point it may be suggested that where ore-deposits occur in connection with pitching anticlines and synclines, that their positions furnish a criterion by which it may be decided

* "The Enterprise Mine, Rico, Colo.," by T. A. Rickard, *Trans.*, xxvi, p. 906, *et seq.*

whether their first concentration was accomplished by ascending or by descending waters. Where the ores occur in pitching arches bounded above by impervious strata, the presumption is that they were concentrated by ascending waters; where the ore-deposits occur in pitching troughs bottomed by impervious

FIG 9.



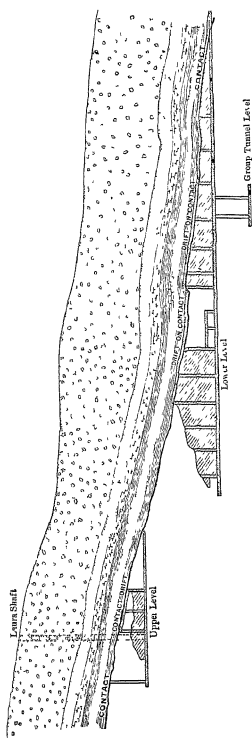
JUMBO No 2 VEIN AT THE CONTACT

Ore below a Gentle Arch of Impervious Shale, where the Feeding Fissure Coming from Below Ends at the Bottom of the Impervious Layer. After Rickard (*Trans*, xxvi, 961, Fig 36).

strata, the inference is that they were concentrated by descending waters, for, as already explained, it is difficult to see how waters can be converged at such positions by moving in the reverse directions. Of course, this criterion cannot be too rigidly applied, for independently of the impervious strata, openings which so frequently occur on anticlines and synclines might

furnish trunk-channels which could be taken advantage of by ascending or descending waters. Thus in the Bendigo gold

FIG 10



SECTION ALONG HIAWATHA VEIN

Scale, 320 feet = 1 inch

Longitudinal Section of the Hiawatha Vein, Enterprise Mine, Colo. Showing the Position of the Ore below an Impervious Stratum, and the Pitch of the Same After Rickard (*Trans*, xxvi, 974, Fig D)

district of Australia, while the more important ore-deposits are in anticlines, occasionally an ore-deposit is found on a syncline.*

* "The Bendigo Gold-Field," by T. A. Rickard *Trans*, xx, 1892, p. 484. See Fig 6, p 475

If the above criterion be applied to the Leadville ore-deposits, the conclusion would be that the sulphides of Leadville were deposited by ascending waters, since they mainly occur on anticlines or anticlinoria below a relatively impervious porphyry and in a much-broken limestone, mainly the blue limestone *. The plates of the Emmons atlas show that the ore more largely occurs on anticlines and on the flanks of the folds than in synclines, although some subordinate synclines on anticlinoria contain ore-bodies. When deposited as sulphides the ores were probably somewhat more uniformly distributed than at present along the base of the porphyries. Later, when the second concentration occurred by downward-moving waters, the material which in many places was on denuded anticlines was in part carried down the limbs of the folds under the porphyry into the limestone. At this time doubtless, also, the limestone would be largely dissolved and the materials would be carried not only down along the dip but across the beds, thus producing the very great irregularities which are characteristic of the bottoms of these deposits. If the above explanation be correct, the Leadville ores would present another case in which both the ascensionists and descensionists have had a part of the truth.†

In this connection it may be suggested that the positions of the ores in reference to the limestone and porphyry in the Leadville district are remarkably similar to those of the ores in the Mercur district in reference to almost identical formations. The forms of the deposits, their irregular under-surface in the limestone, and the regular surface at the porphyry are all identical. Both Emmons and Spurr agree that the ore in the Mercur district was deposited as sulphides by ascending waters. If this be true, the same explanation is probably applicable to the Leadville district.

A pervious layer or other opening furnishing¹ a trunk-channel for circulating waters may be bounded on both sides by impervious strata. In this case the ore-deposit may be produced by ascending or descending waters. But where the strata

* "Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, 1886, chap. vi, pp. 539-584

† "Geology and Ore-Deposits of Iron Hill, Col.," by A. A. Blow, *Trans.*, xviii, 1890, 180

are folded into pitching anticlines and synclines, the positions of the ores with reference to the folds would determine whether the precipitating waters were ascending or descending. An excellent illustration of ore-deposits at the openings of anticlines *between* relatively impervious strata, presumably formed by ascending waters, are the gold-bearing quartz-ores in the slates and quartzites of Nova Scotia, described by Faribault.* Here there are a great many parallel deposits directly at the anticlines or on some parts of the anticlinal folds, the deposits being separated by layers of relatively impervious slate. Furthermore, the largest deposits are located on the great pitching anticlines rather than the subordinate ones.

Porous pitching troughs below an impervious stratum or above an impervious stratum or between impervious strata may have a different origin from those mentioned. Very frequently such troughs are produced in part or in whole by intrusive igneous rocks. For instance, if sedimentary strata have a monoclinal dip and a dike cuts across the strata, a pitching trough may be produced, as, for instance, in the Penokee district.† An intruded igneous rock may follow the contact between folded strata, and thus furnish a trough or arch bounded by an impervious formation. Various other ways will immediately occur to one in which pitching troughs or arches with impervious basements or roofs or both, may be produced. It matters not how the trough or arch be produced, provided a porous stratum or an opening between the layers furnish a trunk-channel, such a trough or arch will be favorable for the concentration of ores. Of course, other favorable conditions must co-operate with these in order to produce an ore-deposit.

Combinations of pervious and impervious strata, united with joints, faults and other structures which affect some impervious strata and do not others, may furnish extraordinarily complex sets of conditions which I am not able to discuss in a general way, but such will undoubtedly yield interesting results when studied in special cases.

* "The Gold Measures of Nova Scotia and Deep Mining," by E. R. Faribault, Paper read before the Canadian Mining Institute, March, 1899. Published by the Mining Assoc. of Nova Scotia, 1899. Pp 11, with plates.

† "The Penokee-Gogebic Iron-Bearing Series of Michigan and Wisconsin," by R. D. Irving and C. R. Van Hise, *Mon. U. S. Geol. Surv.*, No 19, 1892.

Pre-Existing Channels and Replacements.—When it is understood that ore-deposits ordinarily form in trunk-channels, the question as to whether ores are deposited in pre-existing openings or are replacements is easily answered, as a general proposition. It has been shown that solutions cannot be appealed to to explain the original formation of channels (see p 40). The existence of channels for underground circulation must be explained by the original structures of rocks, or by the effects of deformation, as already indicated. It therefore follows that ore-deposits are, to some extent at least, deposited in pre-existing openings. However, the conditions for vigorous circulation are also those for reactions upon the wall-rocks. It has been fully explained that solution and deposition are commonly simultaneous processes. Wherever there is a trunk-channel it is certain that the walls of the openings will to some extent be dissolved, and at the same time or subsequently metalliferous minerals be precipitated. Indeed, either enlargement by solution and subsequent precipitation of ore or synchronous solution and precipitation by which the wall-rocks are replaced in various degrees molecule by molecule by the ore, or both together, are almost universal phenomena.

I therefore believe that the large majority of ore-deposits, if not all, are partly deposited in pre-existing openings and are partly replacements of the wall-rocks. However, in some cases the filling of the pre-existing cavities is the more important or even dominant process, and in other cases substitution for the wall-rocks is the more important or dominant process.

Other things being equal, the main masses of ore-deposits are more likely to be in pre-existing cavities in refractory rocks, such as quartzite, granite and porphyry; and ore-deposits which are largely replacements are more likely to occur in easily soluble rocks, such as limestone. The gold-quartz veins of California give an excellent illustration of the deposition of ores in pre-existing cavities in refractory rocks, such as siliceous argillite, diabase, diorite and granodiorite.* This instance is all the more interesting since the wall-rock itself is greatly modified, and has lost and gained various elements. Ore-deposits which are largely replacements are well illustrated by the

* Lindgren *et al*, pp. 172-257, 259, 261; also pp 146-157.

silver-lead deposits of Eureka, Nevada, and Leadville, Colorado, and by the gold deposits of the Judith mountains, Montana *

Replacements are likely to be important also in proportion as the trunk-channels are complex rather than simple. This follows from the law of mass action. In proportion as a trunk-channel is complex, the surface of action upon the wall-rock for a given quantity of solution is large. As conspicuous examples where there are large surfaces of action may be mentioned sandstones and conglomerates, and the reibungs-breccias or crushed rocks along fault zones. Where the trunk-channels are very complex, the rocks even if refractory may be replaced to a considerable extent by the metalliferous ores. A conspicuous instance of this in a sedimentary rock is that of the copper conglomerate deposits of Lake Superior, where many grains, pebbles and boulders of porphyry are partly or wholly replaced by metallic copper. In some places the metallic copper occurs as partial or complete skulls surrounding the boulders of porphyry, in other places these skulls are thicker, and in still other places the entire masses of the boulders, as described by Pumpelly,[†] are fully replaced by the metallic copper. While the conglomerate deposits of Lake Superior are in part replacements, they also are in large part, fillings of pre-existing cavities between the clastic particles. An excellent example of replacement in igneous rocks where there is complex distributive faulting and thus a large surface of contact for substitution, is furnished by the Cripple Creek district, in which according to Penrose,[‡] ore mainly occurs replacing and blending into various igneous rocks.

In case of substitution the entire mass of the rock may be continuously replaced. This is particularly likely to occur

* "Silver-Lead Deposits of Eureka, Nevada," by J S Curtis, *Mon U S Geol Surv*, No 7, pp 98-99. "Geology and Mining Industry of Leadville," by S F Emmons, *Mon U S Geol Surv*, No 12, pp 556, 569. "Geology and Mineral Resources of the Judith Mountains of Montana," by W H Weed and L V Pusson, *18th Ann Rept U S Geol Surv*, pt iii, 1896-97, pp 594, 598.

† "Copper District," by R Pumpelly, *Geol of Mich*, vol 1, for 1869-1873, pp 37-38. "Paragenesis and Derivation of Copper," by R Pumpelly, *Am Jour Sci*, Third Series, vol ii., 1871, p 351.

‡ "The Mining Geology of Cripple Creek, Colorado," by R A F Penrose, Jr., *16th Ann Rept U S Geol Surv*, pt. ii., pp 140-141, 144-146, 161-162.

where the rock is uniform in structure and composition, as limestone or dolomite. Where, however, the rock is of complex composition such as granite or porphyry; or where there are different kinds of rock present, as, for instance, diorite and granite, the replacement will usually be largely selective. This selective replacement may apply to the mass of the wall-rock, to the individual fragments of it, to clastic fragments of sandstones or conglomerate, to the different constituent minerals in a single fragment. The particular minerals or masses which are most soluble in the solutions present will be most rapidly dissolved.

Where the wall-rock varies greatly in the solubility of its minerals, the selective replacement of the country-rock may extend for some distance from the central deposits. The readily-soluble minerals are dissolved, and in place of them there are precipitated the metalliferous minerals. This process is ordinarily called impregnation. Selective replacement of this kind is well illustrated by the Butte, Montana, granite, in which "the basic constituents of the granite are naturally attacked first, then the feldspars, and finally the quartz itself may be removed, so that in some parts there are found large masses, composed entirely of metallic minerals"*

In the variable solubility of the country-rock lies the partial explanation in regions of heterogeneous rocks of the frequent occurrence of the main masses of the ore-deposit in the more soluble rock. For instance, where limestone and sandstone, limestone and quartzite, limestone and diorite, limestone and trachyte, limestone and porphyry, limestone and granite, or limestone with almost any other rock occur in intimate association and ore-deposits are found, the ore is likely to be largely in the limestone.† The partial explanation of this relation is undoubtedly the more ready solubility of the limestones. However, other factors enter into the matter. It has already been explained that the country-rock may furnish solutions which

* "Notes on the Geology of Butte, Montana," by S F Emmons, *Trans*, xvi, 1888, 57

† "The Copper Ores of the Southwest," by Arthur F Wendt, *Trans*, xv., 25-77 "Silver-Lead Deposits of Eureka, Nevada," by Jos Story Curtis, *Mon U S Geol Surv*, No 7 "Geology and Mining Industry of Leadville," by S. F Emmons, *Mon. U. S. Geol Surv*, No 12, p 540.

react upon the mineral-bearing solutions, and thus cause precipitation (see pp. 62-64). Furthermore, where limestone and stronger rocks are deformed together, the limestone, having less strength, is more likely to be crushed and broken in a complex manner and thus furnish trunk-channels for circulation.

In conclusion, I insist that ore-deposits form where there existed original trunk-channels of circulation. These trunk-channels may have been greatly enlarged by solution. This, indeed, is the general tendency above the level of groundwater, but the general tendency below the level of groundwater is to cement rather than to enlarge the openings (see p. 74). Ore-deposits formed along trunk-channels will commonly, if not universally, be to some extent in pre-existing openings and to some extent as a substitution for the wall-rock. Where the trunk-channels are simple and the rocks are refractory the ore-deposits to a large extent are likely to be in pre-existing openings. Where the trunk-channels are complex and the rocks soluble the ore-deposits to a large extent are likely to be replacements.

Character of the Topography.

Effect of the Vertical Element.—Where the topography is marked the underground circulation is likely to penetrate much deeper than in regions where the variations in topography are slight.

In mountainous and elevated plateau regions the lithosphere is likely to have more numerous, larger, and deeper openings than in low-lying areas. Elevated areas are those of comparatively recent orogenic or epeirogenic movement. Therefore they are regions in which the rocks have recently been deformed and fractured, and hence the processes of cementation would have been less likely to have closed the openings. In regions of very steep topography the tendency for the material to glide down the slope under the stress of gravity also tends to widen openings which have been once formed. Such movements are known to be effective to the depth of hundreds of meters. It is hence clear that elevated and rough regions are those in which the underground circulation is likely to find large, numerous, and deep openings.

Furthermore, elevated and mountainous regions are those in

which the underground water has the greatest difference in head, and this is favorable to deep circulation.

Thus, in mountainous regions, like the Cordilleras, it would be expected that the underground circulation both ascending and descending would be effective to greater depths upon the average, than in regions of gentle topography like that of the lead and zinc district of southwestern Wisconsin (see Fig. 7, p. 146), where it is perhaps probable that the scope of the effective circulation, ascending and descending, is confined to a vertical distance of 500 meters or less.

Unfortunately, the majority of descriptions of mines do not say anything as to the level of groundwater. In the San Juan district of Colorado, which is a region of very rugged topography, Purington states* that the level of groundwater is far below the surface, and that oxidizing effects are produced at a depth of 800 meters or more, thus confirming the conclusion that the zone of descending water is increased by rugged topography, and it can hardly be doubted that the zone of effective ascending circulation is equally increased.

Effect of the Horizontal Element.—The horizontal position of an ore-deposit with reference to topography often has an important influence upon its richness and magnitude. If the correct theory of circulation of underground waters and the deposition of ores has been given, certain corollaries follow from this theory with reference to this point.

(1) Commonly ores deposited by ascending waters would be formed below the valleys, or at least below the lower parts of the slopes, for these are the places where waters are ascending in the trunk-channels. (2) Commonly ores deposited by descending waters would be formed below the crests or below the upper slopes of elevations; for these are the places where water would be descending. Probably the upper slopes would be more favorable places than the crests; for at an annular belt upon the upper slope of an elevation the quantity of descending waters would be greater than at the crests. (3) Commonly ores which receive a first concentration by ascending waters and a second concentration by descending waters would be on the slopes,

* "Preliminary Report on the Mining Industries of the Telluride Quadrangle, Colorado," by C W Purington, 18th Ann. Rept. U S Geol Surv., pt. III, 1896-97, pp. 825-827.

probably in many instances nearer the valleys than the crests. At such places the meteoric waters falling at the higher elevations would have sufficient head to deeply search the zone of fracture for ores. Therefore, the ascending circulation in trunk-channels would be strong. Furthermore, at such places the level of groundwater would be a considerable distance below the surface, and abundant descending waters would be concentrated in the upper parts of the openings. (See Fig 6, p. 81.) The downward migration of the belt of weathering would furnish the final favorable condition for the accumulation of a large amount of second concentrates by descending waters.

Admirable illustrations of ore-deposits corresponding to the second of the corollaries are furnished by the iron-ore-deposits of the Lake Superior region. These are the products of descending waters, and the great majority of the ore-deposits are found near the tops of hills or upon the upper slopes.

An excellent illustration of the third corollary is furnished by the lead and zinc district of the upper Mississippi valley. Chamberlin* notes that in the valleys of the Wisconsin part of the district the waters generally ascend to the surface, therefore, at such places only a first concentration would be expected, and it is the general impression among miners that a lode makes better on the slope of a hill "than at the summit or at the foot of a hill."† Furthermore, it is held by the miners that the lodes which run parallel to a contour of a hill "like an eave-trough," are more likely to be rich than those which run toward the summit of the hill.‡ Both of these practical conclusions of the miners are fully explained by the theory of a first concentration by ascending waters, and a second concentration by descending waters when considered in connection with the topography.

The above conclusions concerning the relations of ore-deposits and topography are only perfectly applicable in regions in which the drainage lines have been reasonably stable. The Lake Superior region and the lead and zinc district of the upper Mississippi valley are regions of stable topography. The main drainage lines have probably not been greatly modified

* Chamberlin, *cit*, p. 585.

† Chamberlin, *cit*, p. 563.

‡ Chamberlin, *cit*, p. 563.

since they were established at the close of the Cretaceous period of base levelling. This is certainly true of the lead and zinc district, but in the Lake Superior region the drainage lines have been to some extent modified by the glacial invasions.

In regions in which there have been recent important changes in the positions of the drainage lines and elevations, the generalizations are only partly applicable. It is well known, in consequence of the varying hardness of rocks, in consequence of their structure, in consequence of the unequal strength of streams and unequal declivity, that drainage lines are almost constantly shifting, and in many regions somewhat rapidly. Consequent on this shifting, many ore-deposits which, when below valleys, received a first concentration by ascending waters, are now well up on slopes or even at crests. A change of this kind would be especially favorable to the development of ore-deposits which are due to two concentrations, the first by ascending and the second by descending waters. In an early stage of the history of a deposit it would be in the most favorable place to receive a first contribution of ore. Later, when, as a consequence of a topographic change, it was on higher ground, it would then be in a favorable place for the work of descending waters. Although it is difficult to prove, I have little doubt that many ore-deposits have had this very favorable history.

Many other ways could be suggested in which changing topography would be favorable or unfavorable to further concentration of ores. However, I shall not attempt this, but suggest that geologists in various regions study the ores in connection with the topographic development of the region. Such studies will furnish facts upon which safe generalizations may be made.

Physical Revolutions

The genesis of many ore-deposits is undoubtedly further complicated by physical revolutions of various kinds. After an ore-deposit has partly formed, either by ascending or descending waters or both, the region may go through a physical revolution, and after the revolution the concentration of the ores may again be taken up by Nature's processes.

After an ore-deposit has been formed the country may be reduced to the level of the sea either by denudation or sub-

sidence, there be deeply buried under sedimentary rocks; may be again uplifted, and undergo a second cycle of reactions which affect the nature of the ore-deposits. An ore-deposit partly formed may be buried deep under volcanic rocks. This undoubtedly has occurred on a great scale through the great period of Tertiary vulcanism in the Cordilleras of the West. The ore-deposits there buried are placed in a new environment, and are undergoing a second cycle of concentration or depletion. When in the future denudation shall have stripped off these volcanics, these ore-deposits will be at the surface. This may not occur while man occupies the earth, but doubtless similar things have occurred with reference to extensive areas where mines are now being worked. It is well known that when fissures once form, these are places of weakness, and that movement has again and again recurred along the old planes. Thus, where the conditions once become favorable for ore-concentration they may recur in the same places through various revolutions. Physical changes of various other kinds may take place. Each of the complex changes in physical history will produce its effect upon an ore-deposit.

General

It is clear from the foregoing that an ore-deposit may not represent the work of a single period of ascending waters, but may include several alternating periods of ascension and descension, and in this way irregularities in certain of the ore-deposits in very ancient rocks may be explained. However, it appears probable in many cases that the main work of ore deposition has been the result of a single concentration by ascending waters and a single concentration by descending waters.

Any of the special and local factors above discussed and others may in an individual case be so conspicuous as to appear to be a controlling factor in the formation of an ore-deposit. One might say that the existence of a given trough was the cause of the production of an ore-deposit. The truer statement would be that the factor under consideration is one essential factor among many. The porosity of a formation, the existence of a pitching trough, favorable topography, the presence of igneous rocks furnishing heat to make the waters active, and many other special factors, may, in a given case, all

be essential factors, without the help of any one of which an ore-deposit would not have been produced. But no combination of these special factors will form an ore-body, if a source of the metal is not available upon which the underground waters may act. In short, each case of the formation of an ore-deposit requires the fortunate combination of many favorable factors, working harmoniously together, the absence of any one of which may prevent the concentration of the ore-deposit.

ORE-CHUTES *

No fact is better known concerning ore-deposits than that they vary in the most remarkable fashion, both in size and richness. Moreover, these variations are both vertical and horizontal. Frequently rich deposits decrease in size or are wholly cut off with extraordinary abruptness. Other equally rich deposits may appear somewhere else on the same level or on another level in an equally strange and apparently inexplicable manner. The ore-masses of exceptional richness are generally called ore-chutes. Sometimes they are spoken of as pay-streaks, at other times as bonanzas, at other times as chumneys. In this paper ore-chute is used as a general term to include all deposits of exceptional richness or size, of whatever origin. At various places in this paper factors have been mentioned which produce ore-chutes. However, because of the very great economic importance of ore-chutes, it seems to me advisable to consider under one heading some of the more prominent of these factors, even at the risk of repetition.

Ore-chutes may be grouped into those which are largely explained (A) by structural features, (B) by the influence of the wall-rocks, and (C) by a secondary concentration by descending waters.

(A) One large class of ore-chutes may be explained principally by structural features. These structural features may be (1) the varying size, (2) varying complexity, (3) flexures, (4) intersections of fractures, and (5) later orogenic movements.

(1) A fracture through a mass of rocks is necessarily uneven. Where there are movements, it follows that the walls will not

For a general discussion of ore-chutes in fissures, see "The Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., *16th Ann. Rept. U. S. Geol. Survey*, part II, 1894-1895, pp. 162-166

be adjusted to each other. Where projections or complex surfaces are opposite each other, the fissure may be represented by a mere seam. Where, on the other hand, depressions or two concave surfaces are opposite each other, a widening may occur which in some cases is sufficient to produce a great room. Rooms may be partly or largely produced by solution. Rooms may be connected by comparatively large channels. Thus there may be in a single mine a succession of rooms filled with rich deposits connected with rich chimneys. It is evident from the above that there may be every variation in the width of an ore-deposit due to this factor, from zero to many feet.

It has been shown, other things being equal, that the underground circulation will follow the largest openings. Thus, wherever there are rooms, and especially where there are rooms with connecting passages of considerable width, there the most abundant circulation will be converged. Moreover, the solutions of this circulation will be derived from various sources. Hence, in the large openings more ore and very frequently richer ore will be deposited than in the narrower openings, where the solutions are both less abundant and less complex.

(2) Ore-chutes are frequent where the fractures, instead of being simple, are complex; that is, where there is a crushed zone, or zone of brecciation and mashing. It has been pointed out (pp. 88-90) that some ore-deposits are largely due to reactions between the solutions and the rocks through which they pass. Such an ore-deposit is most likely to be rich at a crushed zone, where there is every opportunity for much greater interaction between the solutions of the trunk-channels and the rocks through which it circulates than where there is a single fracture, even if the space furnished by the latter is greater than that furnished by the multitude of smaller openings. (See p. 159.)

(3) Very frequently the rich chutes of ore are located by flexures, the ore being either at the crests of anticlines or at the bottoms of synclines. As pointed out (pp. 150-157), this is especially likely to be the case where, in connection with the folds, there are impervious strata. Under such circumstances, as has already been fully explained, ore is likely to be converged from ascending solutions in the arches of pervious

strata below impervious strata, and by descending waters in troughs of pervious strata above impervious strata. In the cases cited, such as those of Australasian and Nova Scotian gold-ores and the Lake Superior iron-ores, these relations are perfectly clear; but doubtless in many mines there are minor flexures which have been overlooked, but which may be sufficient to control the movement of the circulation, and thus produce the chimneys of ore. These minor flexures may be parallel with the dip of a deposit, or they may pitch to the right or to the left of a deposit as one looks down the dip.

(4) The intersections of fractures furnish one of the most frequent explanations of ore-chutes. The intersections may be those of faulted fissures; those of fissures and joints, or the intersections of joints. In many instances one set of fractures carries the larger ore-deposits, and the intersecting set or sets of fractures are known as side fractures. In other instances the main deposits may occur in more than one set of fractures, and still other sets of less importance constitute the side fractures.

In all cases where intersecting fractures occur, there solutions will be contributed from two or more sources. The solutions will invariably have different compositions, and, therefore, precipitation will be likely to occur at the junctions. In some cases more than one set of fractures may furnish metalliferous material, while in other cases the metalliferous material may be contributed by one set of fractures and the precipitating agents by the others. In these instances where the intersecting veins all carry ore, it is easy to see why the deposits at the intersections should be unusually large and rich. However, where the side veins are small or are wholly filled with gangue material, their importance in the genesis of ore-deposits has been very generally overlooked. In many instances there is little doubt that the metallic material has been precipitated in a main fissure at or near where the side veins join through the influence of the solutions contributed by the latter veins. A very clear case of the influence of side veins is that already cited of the Enterprise mine, of Rico, Colorado, where the pay-chutes are especially rich in the main fissures at the places where barren side veins intersect them. Where ore-chutes are found to be connected structurally with barren side veins, a considera-

tion of the minerals themselves and the minerals in the side veins ought to lead to more exact knowledge concerning the manner of the precipitation of the metal, for presumably the precipitation of the metals was connected with some of the compounds which occur as gangue in the side veins

Side fractures may be at right angles to the main set of fractures or incline to them. They may extend directly down the dip or pitch to the right or left along the dip. Therefore, almost any curious distribution of the rich chutes may occur. In some cases a side stream either bearing metals or precipitating agents, or both, may not issue equally all along a fault or a joint, but may be largely converged into a single channel or strong spring which enters a fissure. In such cases, especially if the spring empties where there is a room produced by the structural features discussed under (1), bonanzas may be formed, such as those of the Comstock lode

While the relative influence of the different sets of intersecting fractures is very complex, in an individual mine a close study of the number, order and relations of the fractures and joints, many of which are, perhaps, almost imperceptible, may furnish rules which will enable one to more intelligently search for ore.

Between the two cases of a trunk-channel produced by flexure, described under (3), and by cross fracture described under (4), there is complete gradation.

(5) Late orogenic movements explain certain ore-chutes. After openings have received a first contribution of ore, and are, perhaps, fully cemented by ore and gangue materials, orogenic movements frequently recur, which again fracture the ground and produce openings. Some parts of a deposit may escape fracture, while other parts may be broken. The fracturing of the broken parts may be simple or complex. The complex fracturing may produce zones of parallel fractures, zones of intersecting fractures, brecciated zones, or even zones in which the material is finely mashed. Between the parts of the deposit which have no fracturing and those in which the fracturing is of the most complex sort, there may be all gradations. The fractures may be confined to a narrow belt of a deposit or to one side of it. It may be confined within varying limits laterally or vertically. All of the above statements in refer-

ence to the main deposits apply equally well to intersecting sets of deposits, also, entirely new sets of openings may be produced. Therefore, an ore-deposit which has received a first contribution, and again is subjected to orogenic movements, is in such a condition that it may again receive a contribution of ore material under the same complex laws as at first. This ore material will be distributed in the same irregular manner as that of the first contribution. Therefore, the new material will not only be distributed irregularly, but will be superimposed upon the old material, which also had an irregular distribution, and thus there will be extraordinary variations in richness.

(B) Ore-chutes in many cases are explained by the influence of the wall rocks. It is well known that where ore-deposits intersect a complex set of rocks, that the pay-chutes are likely to have a decided preference for one rock rather than the others. For instance, if a fissure passes from granite to diorite, or from either of these to limestone, or from any of these to sandstone, the character and richness of the deposit may vary greatly as the rock changes. For this variability, due to the character of the wall rocks, different explanations apply in different cases.

(1) In some instances the restriction of the ore-chutes to one rock is largely explained by the more ready solubility of that rock. This is particularly applicable to the substitution deposits, the wall rock being dissolved *puri-passu* with the deposition of the ore. By the solution of the soluble rock sufficient room is furnished for a large ore-deposit. The above is undoubtedly the partial explanation in many cases of the preference of the ores for limestone rather than to the adjacent more insoluble rocks. (2) In other instances the preference of the rich and large bodies to one wall-rock rather than another is due to the fact that the wall rock itself, by reaction upon the solutions, precipitates the ore material. This may also partly explain the preference of certain ore-deposits for limestone. (3) In still other instances the wall rock itself furnishes solutions containing metalliferous material which is precipitated in the trunk-channels, or furnishes solutions capable of precipitating metalliferous material in the trunk-channel.

(C) A third class of ore-chutes are those produced by the processes which have been so fully explained in this paper, viz.:

the secondary enrichment of a deposit by descending waters, the first enrichment of which was produced by ascending waters. By this process rich ore-bodies, either oxidized or sulphuretted, or partly each, which are limited in depth by the distance to which the descending waters are effective, are formed.

General.—Of necessity, in this analysis, the various factors which may produce ore-chutes have been separately treated. However, in a given case it is rare, indeed, to find that the entire explanation lies in the application of a single one of them. To explain an ore-chute of an individual mine, ordinarily a number of the above causes need to be combined, and in some cases, doubtless, other causes which have not been treated. No study is more important economically, more fascinating, or more difficult in a given district or mine than to ascertain the particular combination of factors which produce the ore-chutes.

From the foregoing it is plain that no general statement can be made in explanation of ore-chutes. In each individual district, more, in each individual mine, still further, in each individual part of a mine, all the phenomena there occurring must be closely studied in the light of a correct theory of ore-deposition in order to reach an explanation applicable to the particular case.

It is well known in the districts which are mineralized that the workable ore-deposits are ordinarily confined to relatively small areas, although, so far as one can see, the amount of metalliferous material to furnish ore-deposits may have been the same throughout the districts. The explanation of the lack of workable ore-deposits for larger parts of the districts ordinarily lies in the lack of the favorable combination of the various special factors mentioned, and doubtless many others which have not been considered. As better illustrating my meaning, I may again mention the iron-ores and copper-ores of the Lake Superior region. The iron-bearing formation has an extensive occurrence throughout the Lake Superior region. The workable iron-ores are, however, confined to small areas, in which there have been happy combinations of ancient and recent metamorphism combined with favorable structural features. The Lake Superior copper-deposits equally well illustrate the principle. All of the mines now being exploited are confined to an exceedingly narrow area on Keweenaw Point. But the

copper-bearing rocks occupy an extensive area about the entire Lake Superior basin. Moreover, these copper-bearing rocks are mineralized in many places, as is shown by the widely disseminated copper. But, unfortunately, in many areas a little copper is concentrated in many amygdaloid or sandstone belts rather than in a single amygdaloid or sandstone. For instance, in certain districts scores of amygdaloid beds lie upon one another. The scoriaceous upper surface of each of these beds bears metallic copper, but none of them in sufficient amount so that the copper is a workable deposit. Had the copper deposited in a number of these amygdaloid formations been concentrated in one of them, a workable ore-deposit would have been produced.

From the foregoing it is clear that an investigation of the local factors in a district should include both those which are favorable to concentration of ores and those which prevent the concentration of ores, for a study of the latter in many districts may prevent the expenditure of large sums in exploration where the mineralization is general but the conditions are not such as to have concentrated the valuable material in sufficient quantity at any one position to warrant exploitation.

A treatise on ore-deposits, including descriptions of individual districts, necessarily deals in each area with the special factors which are important in that district. These special factors may be considered so conspicuous that the entire attention is given to them. However, it is to be remembered that each of these is subordinate to the general principles controlling the deposition of ore-deposits in all districts.

THE CLASSIFICATION OF ORE-DEPOSITS.

Before giving the classification of ore-deposits which follows from the foregoing treatment, it may be well to briefly recall the most fundamental features of the water circulation which produces the ore-deposits. First comes the action of the downward-moving, lateral-moving waters of meteoric origin which take into solution metalliferous material. These waters are converged in trunk-channels, and there while ascending the first concentration of ore-deposits may result. After this first concentration, many of the ore-deposits which are worked by man have undergone a second concentration not less important

than the first, as result of descending, lateral-moving waters. In other cases a concentration by descending, lateral-moving waters alone is sufficient to explain some ore-deposits. It, therefore, appears more clearly than heretofore that an adequate view of ore-deposits must not be a descending water theory, a lateral-secreting water theory, or an ascending water theory alone. While an individual ore-deposit may be produced by one of these processes, *for many ore-deposits a complete theory must be a descending, lateral-secreting, ascending, descending, lateral-secreting theory.* The descending, lateral-moving, and ascending waters are alike driven by gravity. Each performs its own work.

We have now only to bring together in summary the different groups and classes of ore-deposits which have been considered to have a satisfactory genetic classification of ores deposited by underground waters. As already noted, ore-deposits may be divided into three groups. (A) ores of igneous origin, (B) ores which are the direct result of the processes of sedimentation, and (C) ores which are deposited by underground water.

Since the ores produced by igneous agencies and those produced by processes of sedimentation have not been considered in this paper, a subdivision of these groups will not be attempted.

Ores resulting from the work of groundwater, group (C) above, may be divided into three main classes:

(a) Ores which at the point of precipitation are deposited by ascending waters alone. These ores are usually metallic, or some form of sulphuret; but they may be tellurides, silicates or carbonates.

(b) Ores which at the place of precipitation are deposited by descending waters alone. These ores are ordinarily oxides, carbonates, chlorides, etc.

(c) Ores which receive a first concentration by ascending waters and a second concentration by descending waters. The concentration by ascending waters may wholly precede the concentration by descending waters, but often the two processes are at least partly contemporaneous. The materials of class (c) comprise oxides, carbonates and chlorides above the level of groundwater, and rich and poor sulphurets, tellurides, metallic ores, etc., below the level of groundwater. At or

near the level of groundwater these two kinds of products will be more or less intermingled, and there will frequently be a transition belt of considerable breadth.

How extensive are the deposits of class (a) I shall not attempt to state. Indeed, I have not such familiarity with ore-deposits as to entitle me to an opinion upon this point. However, a considerable number of important ore-deposits belong to this class. This class is illustrated by the Lake Superior copper-deposits.

The ore-deposits of class (b) are important. Of the various ores here belonging, probably the iron-ores are of the most consequence. A conspicuous example of deposits of this kind are the iron-ores of the Lake Superior region.

It is believed that the ore-deposits of class (c) are by far the most numerous. I suspect that a close study of ore-deposits in reference to their origin will result in the conclusion that the great majority of ores formed by underground water are not the deposits of ascending waters alone, but have by this process undergone a first concentration, and that descending waters have produced a second concentration, as a result of which there is placed in the upper 50 to 500 or possibly even 1000 meters of an ore-deposit a large portion of the metalliferous material which originally had, as a result of the first concentration, a much wider vertical distribution.

To the foregoing classification objections will at once occur. It will be said that there are no sharp dividing lines between the groups and classes. To this objection there is instant agreement. Transitions are everywhere the law of nature. In another place* I have explained that there are gradations between different classes of rocks, and this statement applies equally well to ore-deposits. I even hold that there are gradations between ore-deposits which may be explained wholly by igneous agencies, and those which may be explained wholly by the work of underground water, or by processes of sedimentation. Ore-deposits which have received a first concentration by igneous agencies or by processes of sedimentation are sure to be reacted upon by the circulating underground waters, and thus a second, or even a third concentration may take place.

* "The Naming of Rocks," by C. R. Van Hise, *Journal of Geol.*, vol. VII, 1899, pp. 687-688.

The first concentration by igneous or sedimentary processes may be the more important or dominant process, or the additional concentration or concentrations by underground waters may be the more important or dominant processes. In some cases, therefore, the ores may be referred to as produced by igneous agencies, in others as produced by processes of sedimentation, in others as produced by these in conjunction with underground waters, and in still others as produced mainly by underground waters. Moreover, there will be found to be undoubted gradations between the different classes of deposits formed by underground waters. Ore-deposits which are precipitated almost solely by ascending waters will grade into those in which descending waters have produced an important effect, and thus there will be transition between classes (a) and (c). Similarly there will be every gradation between classes (a) and (b), and between classes (b) and (c). If this be so it will not infrequently happen that a single fissure may fall partly in one class and partly in another. Thus, a single ore-deposit may belong partly in class (a) and partly in class (c). However, in most cases a deposit will primarily belong to one of the three classes. Indeed, not only are there gradations between different varieties of the ore-deposits among themselves, but there are gradations between the ore-deposits and the rocks, for the ore-deposits, in many cases, are not sharply separated from the country-rocks, but grade into them in various ways.

In answer to the above objection concerning gradations, it may be said that I know of no classification of ore-deposits which has yet been proposed to which the same objection may not be urged with equal or greater force.

However, this retort does not give any criterion by which the usefulness of the above classification may be tested. The test is, does this classification give us a more satisfactory method of studying ore-deposits than has heretofore been possible? Will an attempt to apply this classification assist mining engineers and geologists in accurately describing ore-deposits? Will the classification, to a greater extent than any previous one, give engineers rules to guide them in their expenditure in exploration and exploitation? By these criteria I am willing that the classification shall be tested.

As an illustration of the practical usefulness of the classifica-

tion, is the connection between genesis and depth. Where the ores are deposited by ascending waters alone it has been pointed out that this is favorable to their continuity to great depth. Therefore, where a given ore-deposit has been shown to belong to this class, the expenditure of money for deep exploration is warranted. Where a deposit is produced by descending waters alone, the probable extent in depth is much more limited. In such cases, when the bottom of the oxidized product is reached, it would be the height of folly to expend money in deep exploration. Where the ore-deposit belongs to the third class, that produced by ascending and descending waters combined, there will again be a richer upper belt which we cannot hope will be duplicated at depth. However, this class of deposits may grade into first class, and after the transition the deposit may be rich enough to warrant exploitation at depth; but if such work be undertaken it must be done with the understanding that the rich upper products peculiar to the belt of weathering will not be reduplicated at depth. It, therefore, appears to me that the determination to which of the classes of ore-deposits produced by underground waters a given deposit belongs has a direct practical bearing upon its exploration and exploitation.

It is my hope that mining engineers and geologists will study ore-deposits in various regions in reference to the principles discussed in this paper. It appears to me that he who does this will be capable of interpreting better than before the phenomena which he finds in the ore-body or bodies with which he is particularly concerned. Of course, it is fully understood that few ore-deposits will illustrate all of the principles above given. It is appreciated that for a certain ore-deposit some few of the principles given on the foregoing pages may be the dominating ones, and that others are unimportant. But this is precisely what I should expect.

In addition to the points specially emphasized in this paper, accurate descriptions should be made of the relations of the different minerals of ore-deposits; of the occurrence of each mineral with reference to the wall-rocks; and their variations in composition, relations and richness at various depths, reckoning both above and below the level of groundwater. Moreover, such a study should include close observation of the

gangue-minerals in their relations to one another and to the valuable minerals, for in many instances they may give important testimony as to the origin of the ore-deposit. In this paper, the gangue-minerals have been altogether ignored. Furthermore, a study should be made of the changes of country-rocks and wall-rocks. When a comprehensive study of various ore-bearing districts has been made, including all of these factors, and the special factors discussed on pp 138-166, it is believed that a more satisfactory treatise upon ore-deposits may be written than has yet appeared.

Such a study of ore-deposits must be a difficult one, involving as it does, a working knowledge of petrography, of mineralogy, and of modern physical chemistry. Undoubtedly, the story of many ore-deposits will be found to be exceedingly complex, and not to come fully within the scope of the principles discussed in this paper. So far as any ore-deposit fails to do this, it will give us data upon which to state a more nearly complete theory of ore-deposits than that here proposed.

The Secondary Enrichment of Ore-Deposits.*

BY S F EMMONS, WASHINGTON, D C

(Washington Meeting, February, 1900)

It was said by many who discussed Professor Posepny's admirable paper on the "Genesis of Ore-Deposits," read at the Chicago meeting of the Institute, in 1893, that its most valuable feature was the clear distinction which it drew between the influence upon ore-deposits of the "vadose" circulation of waters descending directly from the surface, and that of the deep underground circulation of waters generally coming from the depths, and assumed by the author to be ascending through more or less open spaces under the influence of heat. A little later the effect of the oxidizing action of the vadose circulation upon ore-deposits was ably and exhaustively treated by Prof. R. A. F. Penrose, in a paper on "The Superficial Alteration of

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Ore-Deposits"*—the only one, so far as I know, which has been exclusively devoted to this important subject.

My own first detailed study of ore-deposits was made at Leadville, in 1880, at a time when almost the only minerals visible in those deposits were in oxidized forms. That this form was the result of the alteration of earlier sulphides by surface-waters had to be proved at the time by induction or analogy, the general correctness of which was, however, abundantly confirmed by subsequent developments. Thus I was early impressed with the importance of distinguishing, in the study of an ore-deposit, the alteration-products, resulting from the action of oxidizing waters descending from the present surface, from the earlier-formed sulphides; and, assuming that the latter were primary or original, I called the former secondary. I also went so far as to say† with regard to oxidized ores passing into sulphides in depth

"So generally is this accepted as a rule in ore-deposits that it would require special demonstration to prove beyond a doubt that the native metals or their oxides and chlorides (except perhaps gold, tin, and the platinum group of metals) are, in any particular case, original, and not the result of secondary alteration from sulphides."

Admitting fully the general truth of the statement that the descending surface-waters exert an oxidizing action, and hence that oxidation-products within the reach of surface-waters are the result of alteration by the latter, I have been led to believe, by observations now extending over a considerable number of years, that, under favorable conditions, the oxidation-products may be changed back again into sulphides and redeposited as such, thus producing what may be called a sulphide-enrichment of the original deposits. Penrose, perhaps, admits this when he says that "the action of surface influences is, in rare cases, one of reduction, which, however, often follows a previous oxidation;" but he gives no instances, and apparently has in mind only those cases in which oxides are reduced to sulphides in the presence of organic matter. Posepny, on the other hand, strong in the conviction of the correctness of his theoretical views, does not recognize any exceptions to the general rule. With him, apparently, the fact that a deposit

* *Jour. Geol.*, vol. ii, April-May, 1894, pp. 288-317

† *U. S. Geol. Sur.*, Mon. xii, p. 562

consists of sulphides is sufficient proof that it has been made by the ascending currents of a deep underground circulation, and cannot have been made by vadose or descending waters. Being rather a searcher after facts than a theorist, I am not deterred from accepting what may appear to me the correct reading of observed facts because it seems to contradict generally accepted theories

In geological observation, however, especially underground, where the field is often very limited, it is not always possible to be certain of the correctness of one's interpretation of a given phenomenon, especially when one is confined to a single district or group of mines. Another observer might construe the evidence otherwise. It is only by multiplying observations in different and widely separated localities, and by finding in all the same sequence of phenomena, to which the same interpretation applies, that one arrives in time at what may be considered, from a geological standpoint, a reasonably certain conclusion.

In the present case, I could have wished to multiply my observations much further, and to obtain more light upon the probable chemical processes involved than I have as yet been able to find in chemical literature, before committing myself to a public statement with regard to them. I have hoped, moreover, to have some experimental chemical work carried on upon lines suggested by my observations in the laboratory of the U. S. Geological Survey; but the limited force and space available for such work have rendered it thus far impracticable

I find, however, among many mining engineers an increasing conviction that the rich concentrations found in many deposits of both copper- and silver-ores, are the results of secondary enrichment. Moreover, Mr. Walter H. Weed, who was associated with me in the geological study of the Butte region in 1896, and, during the summer of 1899, in underground work there, submitted at the recent meeting of the Geological Society of America, an article on the "Enrichment of Mineral Veins by Later Metallic Sulphides,"* which contains much that I had intended to write on the subject. Hence, I feel it necessary, in self-defense, to publish something in the nature of a *caveat*,

to show that my attention has been directed to this subject for some time past, even though the evidence for the conclusions I have reached is not yet as complete as I could wish.

PREMISES OF BELIEF

To avoid misunderstanding it may be well to state, at the outset, the premises of my belief. In the first place, I eliminate from this discussion the ore-deposits formed exclusively by magmatic differentiation, and first brought into prominence by the Scandinavian geologist Vogt—not that I deny the importance of this mode of ore-concentration as a possible first cause, but because, in my 20 years' study of ore-deposits, I have not yet had an opportunity, as I have elsewhere stated,* of seeing any which were not due, in the condition in which they now exist, "to further concentration, perhaps many times repeated." Hence, I assume that the majority of ore-deposits, as at present found, owe their existence to the agency of circulating waters; and it is of these only that I speak in this paper.

Circulating Waters of Surface-Origin.—I am inclined to limit my subject further by excluding those water-formed deposits, which, according to the theory of some French geologists, have been deposits from solution in waters originating or occluded in igneous magmas, or, as the Scandinavian geologists express it, by pneumatolysis, since such waters cannot have formed an essential part of the circulation, properly speaking.

I have found no reason to change essentially my early belief that the waters which have been the principal agents in forming ore-deposits came originally from the surface. As I then expressed it:†

"There are, therefore, both upward and downward currents, it being generally assumed that the latter are surface-waters sinking under the influence of gravity, and the former, the same waters rising under that of the internal heat of the earth."

Rickard uses a very suggestive, though homely metaphor, to illustrate the manner of this circulation, when he says.‡

"We may compare the circulation of water up and down through the earth's rocky exterior, to that of the ordinary heater in a house. The water circulates,

* *Trans.*, xxiii, 599

† *U S Geol. Sur.*, Mon. xii., p. 570.

‡ *Trans.*, xxiv, 950.

because, when hot, it rises through the length of pipe, and, when cool, it falls back to be reheated "

It is the difference of temperature produced by internal heat that causes the water to rise, though gravity is still the impelling force, since the colder surface-water is descending to take the place of that which rises. Only occluded water could find its motive power, independently of gravity, in the rock-mass in which it originated

Groundwater-Level —Posepny, as I have already remarked, has strongly emphasized the distinction between the vadose or descending circulation and the profound or ascending circulation, the separating line between which is called the groundwater-level. Lest my statement that he did not recognize the formation of sulphides by the vadose circulation may be deemed too sweeping, I will quote (not finding a direct declaration on this point from him) Dr Raymond's exposition of his meaning.*

"2 Concerning the condition (the vadose circulation above groundwater-level) which is most open to our observation, we know a great deal. We know, for instance, from an overwhelming number of observations, that the solutions of the vadose circulation are oxidizing, and that (apart from the, probably rare, reformation of sulphides by the action of organic matter) they do not precipitate sulphides, but, on the contrary, attack and decompose them "

It is evident from Posepny's remarks on different deposits (*e g*, those of Wiesloch, in Baden†), that this is a correct presentation of his views. While this distinction of Posepny has been very useful, undoubtedly giving to many students a clearer conception of the relative influence of waters descending from the surface, and those arising from the depths, I believe that in this, as in most geological generalizations, the lines should not be drawn too strictly, but must be susceptible to considerable modification under varying conditions. Inasmuch as both ascending and descending currents are part of the same general circulation, there must also be a vast amount of nearly horizontal or lateral movement. Moreover, in our western mountain-regions the groundwater-level is not, so far as my experience goes, the definite horizon predicated by Posepny, which bears a comparatively uniform relation to the existing surface; nor is the oxi-

* *Trans*, xxiv, 982.

† *Trans*, xxiii, 259

dizing influence of surface-waters always strictly confined to the region above it.

Very early in my studies of ore-deposits, in writing on a typical instance of the secondary alteration of ore-deposits, I defined the groundwater-level thus *

"The permanent water-level at any point beneath the earth's crust, and within the range of human observation, is evidently that level to which water will rise by the filling of a hydrostatic basin (which may consist of any system of channels permitting its ready circulation, such as joints, fissures, bedding-planes or porous rocks) up to the point of its overflow, or where it would drain out either to the surface or into another hydrostatic basin. The water filling such basins is originally supplied from the surface, but after a comparatively long passage through the rocks, during which its oxidizing agencies, such as air, organic acids, etc., may be supposed to have become neutralized, or to have exhausted their power upon the rocks through which they have passed. The water or moisture which furnishes the active agencies of secondary decomposition of ore-bodies must, on the other hand, come to them directly from the surface, and not be neutralized by a long passage through rock-material, or by mingling with a large body of already neutralized water, such as that which exists below the water-level. This seems to me to be the explanation of the fact that surface-waters act as oxidizing agents above water-level, and as a protection against such action below the water-level."

Since then, I have observed many instances in which the zone of oxidation, as defined by the water-level, is not a generally even surface, more or less conformable to the surface of the ground. The most striking that I recall now, is in the Tintic district of Utah, where, in the deposits in the limestones, the limit of oxidation had not been reached at 1600 ft. below the surface, while, in veins in the igneous rocks, scarce half a mile away, the groundwater-level and zone of unaltered sulphides were met within 200 to 300 ft. of the surface.

Deposition of Oxides below Water-Level.—Winchell calls attention to a striking instance of oxidizing action extending below the groundwater-level when in his discussion† of Posepny's paper he speaks of the Lake Superior iron-ore deposits.

"The ore-lenses lie in basins of greenstone schists or other rocks, and occur at various depths to at least 2000 feet. At the lower edges of some of these lenses are found deposits of silica, kaolin, etc., which have plainly been removed from the ore-body above in process of concentration. This is much below the vadose circulation, as the immense pumping-engines and the rivers of water which they throw the year round testify, but it is an instance of the formation of ore-deposits on the largest scale by descending waters."

* *Proc. Colo. Sci. Soc.*, vol. II, Part II, p. 102, 1886.

† *Trans.*, XLV, 959.

In my own experience, I have met many instances of oxidizing action below the groundwater-level, but nothing on the scale of these Lake Superior deposits. They were generally very local in their development, and I have been accustomed to look, with more or less success, for their cause in a recently formed water-channel down which the surface-waters were able to descend freely and with relative rapidity.

It is not, however, the oxidizing action of surface-water that is in question here, though that process is highly interesting, and has had great influence upon the relative richness of ore-bodies. Moreover, notwithstanding our pretty clear comprehension of it, many new data might be cited concerning it. But the question under discussion is, to what extent sulphides may be deposited from descending surface-waters, and under what conditions.

Deposition of Sulphides.—Prior to my studies at Butte in 1896, I am free to confess, I had not given much thought to the possible deposition of sulphides from surface-waters. The fact that, in the presence of organic matter, oxides may be reduced to sulphides was of course well known; and the few instances of the formation of pyrite in this manner that came under my observation, were noted as curiosities rather than as matters of economic importance. The sulphides that I found within the oxidized zone and distinctly above the groundwater-level (mostly small masses of galena and pyrite, but in some cases very considerable bodies of the latter) were generally explainable as material so dense that oxidizing waters had not yet penetrated into the interior of the mass, and were, to my mind, simply an additional proof that the groundwater-level was not an absolute line of division between oxides and sulphides, but that under favorable physical conditions the latter might exist above it, as the former could extend below it. There were, it is true, occasional occurrences that could not be explained on the ground of imperfect oxidation through physical obstacles, and these were stored in my memory, until sufficient evidence should have accumulated to indicate some general explanation. Of such was the observation made during my Leadville work,* that, in the kernels of partially altered galena surrounded by a crust of cerussite, which were found in

* *U S Geol Sur*, Mon XII, p 553

the oxidized zone, the galena was abnormally rich in silver, containing more than five times as much as did the cerussite resulting from its alteration, the tenor of silver in which was nearer to the normal or average proportion

In the same way, according to Blow,* "the small seams found penetrating the limestone at the bottom of the ore-body are often formed of galena-ore, and are always richer than the lead-sand and cerussite-ore above" In these cases it is evident that the action of the surface-waters has been to concentrate the silver in the sulphide-ore, not in the oxidized product

Again, the oxidized ores observable at the time of my study of the Leadville deposits carried abundant iron, lead and silver, but scarcely a trace of zinc, yet it was assumed, and soon found to be the fact, that the sulphide-ores consisted of mixtures of pyrite, galena and zinc-blende, the latter in fairly equal amount The far greater solubility of the zinc-salts, over those of lead, would account for the latter's remaining to a great extent in their original position; but the question was, what had become of the zinc? Mining in the sulphide-bodies in later years has shown that, immediately below the zone of oxidation, the bodies of mixed sulphides are far richer in zinc-blende than the average of those enormous bodies mined at greater depths Blow, as a result of his nine years' work in the ore-bodies of Iron Hill, draws the following conclusion from these facts †

"It seems probable that a large proportion of the zinc, which was totally removed from the carbonate ores, has been redeposited as a sulphide, and principally just below the line of complete oxidation, by surface-waters, and such redeposition has advanced and increased *pari passu* with the limit and extent of such oxidizing action"

There are many other instances in which suggestive remarks have been made upon the probable deposition of sulphides by descending surface-waters, as will be shown later Most pertinent at the present moment is that made by our President, Dr. James Douglas, in 1890,‡ with regard to the Butte copper-mines. In speaking of the vertical distribution of the various kinds of ore, he says

"It seems as if the copper, leached out of the four hundred feet of depleted vein, had been concentrated in the underlying ore, and had thus produced a zone

Trans, xviii, 169

† *Trans*, xviii, 172

‡ *Trans*, xix, 693

of secondary ore about two hundred feet deep, which contains, as might be expected, about thrice its normal copper contents "

Such suggestions as these are useful, however, rather as confirmatory data, and hardly form a sufficient basis on which to found any definite generalization or theory. For this, one needs to have the results of a systematic study of an important district, based on accurate and detailed maps, on which the underground observations are worked out with the aid of careful microscopic and chemical examinations of the material gathered

INSTANCES OF SECONDARY ENRICHMENT

It was during the study, in 1896, of the Butte district, and especially of its copper-bearing veins, that such definite evidence of the secondary enrichment of sulphides on a considerable scale was first obtained by me

Conditions at Butte.—The following is a brief statement of the conditions which presented themselves as a result of these studies at Butte. There is evidence in this district of several successive rock-fracturing movements. In regard to the earlier movements which produced the primary sulphide-deposition it is not always possible to differentiate clearly one from the other in point of time. It is, however, possible to distinguish another set of fractures, which I have called secondary* or post-mineral fractures, because they are distinctly later than the original deposition of sulphides, since the fissures contain within them dragged-in and more or less rounded fragments of these sulphides together with quartz and country-rock.

There are two sets of secondary fractures or faults first, those which run east and west, and are generally parallel to and more or less coincident with the original east and west vein-systems, which I have called "strike faults," and, second,

My use of the word "secondary" in this connection has been criticised as liable to misconstruction, because it has hitherto been used to designate the alteration by surface-waters, and applied exclusively to oxidized forms of mineral-deposition. It is further said that one has no right to assume that only one fracturing and ore-deposition has preceded those thus designated "secondary." While admitting the force of these criticisms, I have been unable to find another satisfactory word, because I am not yet sure in my own mind that all the successive processes that have taken place in these deposits are known, and having committed myself to the use of this word in print, think it best to continue it until our knowledge is more complete.

the transverse fractures or cross-faults which strike between northwest and northeast, and have, as a rule, a shallower dip than the east and west fractures. The second class have caused an evident displacement of the veins, sometimes amounting to several hundred feet. Whether the first have been accompanied by any considerable movement of displacement cannot be determined on account of their parallelism to the veins. No definite proof has yet been found to determine whether the two systems of fractures were formed contemporaneously or not, my general impression has been that the shattering of the country was produced by successive dynamic shocks of increasing intensity, which first formed fractures along the lines of the existing vein-systems, with slight movements of displacement and consequent shattering and grinding of the material traversed, and finally resulted in a cross-fracturing accompanied by a certain amount of lateral displacement of veins. The strike-fractures or faults, which, in the nature of things, are the most open to observation, being constantly exposed by the mine drifts, vary in size from thin clay-selvages to broad breccia-zones up to 15 or 20 feet thick, but are most commonly seams a few inches thick carrying small rolled fragments of granite, quartz and ore in a soft, wet kaolin-mud. They are found in foot- or hanging-wall, or within the vein itself, often several to a given cross-section, and extend in depth as far as the explorations have yet reached. Except in the case of a few breccia-zones within an original vein-system they do not ordinarily carry pay-ore.

The cross-fractures or faults have been quite extensively developed since our field-work was completed as the result of the many law-suits that have sprung up in the district, and have been carefully studied by the many experts engaged in investigating the geological conditions bearing upon the different questions in dispute. In some cases they are known only as planes of movement cutting off the veins; in others, they have been found to contain so much dragged-in ore from the various veins they cross, as to constitute valuable ore-bodies. In the opinion of some of the experts, they also contain considerable newly-deposited ore in the sulphide form. This, I have not yet had an opportunity of verifying from personal observation.

Paragenetical study of the ore-deposits shows that the earli-

est-formed minerals are quartz, pyrite, chalcopyrite and enargite. Enargite is in some cases later than chalcopyrite. Veins composed mainly of enargite have been found cutting the siliceous pyritic veins. The richer sulphides, bornite, chalcocite and covellite, which, with enargite, constitute the most valuable ores of the middle levels of most of the mines, are of later origin, their order of deposition being, as far as microscopic observations enabled us to determine, that in which they are named. Little opportunity was had of studying the oxides and carbonates of copper which are characteristic of the zone of oxidation, and would normally be considered of an entirely later formation.

The prominent characteristics of the Butte copper-lodes are, first, an upper oxidized zone extending down from 200 to 400 feet from the surface which contains less than 1 per cent. of copper on the average, the value being principally in silver. It is a mass of crumbly, honeycombed quartz, singularly free from metallic oxides when one considers the great mass of the original sulphides found in the veins in depth. Second, below this is a rather ill-defined zone characterized by great values in the rich copper sulphides, bornite and chalcocite or copper-glance, associated with pyrite and chalcopyrite. The proportion of these rich sulphides gradually decreases with depths until in some mines the ores consist only of pyrite with a slight admixture of chalcopyrite. Enormous amounts of copper-glance were found in many of the mines, generally in the upper levels of the sulphide zone. Sometimes they constituted solid masses fifteen feet or more in thickness, in which, however, close examination showed a sprinkling of chalcopyrite or pyrite in minute, irregular, and often pitted grains throughout the mass of the glance; not infrequently the cleavage faces are coated with very thin films of native-silver.

The fact that struck me most forcibly with regard to the rich bodies of glance, was that one or more secondary fractures are invariably found in their immediate neighborhood, though not necessarily in direct contact with them. In a few instances, at depths of a thousand feet or more, considerable bodies of the richer sulphides were found within a breccia zone. The largest masses of the comparatively rare mineral, covellite, were found on the 1100-foot level of the East Gray Rock mine lying in a

mass of breccia, with a kaolinized clay matrix so soft that it would run when opened. In the comparatively solid veins, however, glance is generally found as a streak a few inches to a foot or more in width, grading off into siliceous pyritous ore, with a thin secondary seam near it, sometimes in foot- or hanging-wall, more often in the vein-matrix itself. This is rather a bald statement of the leading facts which led me to the conclusion that there is a genetic connection between the secondary fractures and the rich copper sulphides; a conclusion that is confirmed, so far as I know, by all geologists who have had opportunities of studying these veins. It is generally agreed that most of these sulphides are enrichments of the earlier vein-deposits by solutions that followed the water-channels afforded by some of the secondary fractures.

The next question that presents itself is, whether this enrichment was produced by vadose, or by deep underground-waters; in other words, from waters that have been descending through the oxidized portions of the lode, or from a new set of ascending currents acting since the secondary fractures were formed. Although, at the time of the publication of the Butte Folio, there were many facts that pointed to the former conclusion, I hesitated to give a decided opinion on the question; first, because of the unfavorable influence it might have on mining in general, and copper mining in particular, especially in this important district (for some might be led at once to adopt the conclusion that the rich sulphides would not be found in depth beyond the reach of such descending currents); and in the second place, I wished to accumulate more knowledge myself before propounding a theory so distinctly opposed to that generally received.

The deposits of Butte are exceptional, so far as my experience goes, in the depth to which the richer copper sulphides have been found to extend, for, though not forming the large bodies they did at 200 to 400 feet below the water-level, they are still found here and there at 1500 feet or more below this level, though in apparently decreasing amount as compared with the immense thickness of pyritous ore.

It should be noted in this connection, however, that there is evidence that the groundwater-level was once very much lower than it is at the present day. It is proved quite con-

clusively by Mr. Weed's surface studies of the region that the granite hills to the east of Butte, known as "East Ridge," and which rise abruptly about 2000 feet above Meaderville in the valley of Silver Bow creek, owe their present elevation to a north and south faulting along their steep western face. The evidence of faulting and consequent relative change of level between the area in which the mines occur and the adjoining East Ridge is mainly derived from the physiography of the region beyond the latter to the eastward, but it is confirmed by the discovery, through mine-shafts, that the actual rock-bottom of the Meaderville portion of Silver Bow valley slopes downward nearly to the foot of the steep western slope of the ridge, reaching a depth of 300 to 400 feet below the surface of the present valley opposite Meaderville, and probably a still greater depth further south. This old depression, which seems independent of present drainage-systems, is now filled up by talus from the East ridge. Its rock-surface was once probably higher than the eastern face of the East ridge, and formed a continuous slope with it, although the actual date and the amount of the displacement caused by the faulting cannot be accurately determined. It must have occurred in comparatively recent time, geologically speaking, and have caused a raising of the water-level in the depressed region, or area, of the present mines, of as much as 1000 or 2000 feet. This fact is mentioned to show, that, even if the objection generally presented to the possibility of the descent of oxide-bearing waters below the groundwater-level be admitted to be valid, it would not necessarily prove that the sulphides, at present below that level, could not have been enriched by descending waters, since before the faulting they may have been above it.

Since my first examination of Butte, I have had opportunities of seeing most of the important copper-deposits of the West, and my associate, Mr. Weed, has visited many in the Appalachian region; I have also examined the literature of the subject for facts bearing upon the question under consideration. Although no case has come under my notice in which the development of secondary sulphides has been comparable, either in extent or in amount, with that of Butte, a brief mention of the prominent facts is made as confirmatory evidence.

Western Copper-Deposits—In the first place, it should be

stated that the occurrence of a belt of rich sulphides immediately below the water-level is by no means universal. It is not found, as far as I know, in the massive pyrrhotite-deposits of Canada, in which one passes directly from a relatively thin gossan into unaltered copper-bearing pyritous ore. The most obvious explanation of their absence there would at first appear to be the cold climate and the comparatively recent planing off of the surface by the continental ice-sheet. I should be inclined to consider the dense character of the material of the deposits, and the possible absence of recent fractures, which would have admitted an easy access of surface waters, as equal, or possibly more important factors.

In the arid climate of Arizona and New Mexico, on the other hand, and still more in Old Mexico, it is often difficult to find the zone of unaltered sulphides, so deep has the oxidizing action penetrated. A recent note on the mines near Mapimi in the State of Durango states that this zone had not been reached at a depth of 2500 feet *

Wendt, in his review of the copper-deposits of Arizona and New Mexico,† makes some very suggestive remarks as to the chemistry of the deposits, though he does not always seem to appreciate to their full extent their geological bearing. He notes, as a general fact, that the ores in limestone are mainly carbonates and oxides, while, in the comparatively acid eruptive-rocks at corresponding levels, they are more likely to be sulphides. In several cases he suggests the probability of secondary migrations. For instance, with regard to the limestone-deposits of the Bisbee district, he says •†

“Contrary to the generally accepted theory of the occurrence of oxidized copper-ores, the writer has doubts whether the ores of this district, as far as known, have ever been sulphurets in their present position. The whole deposition tends to prove that the ores are not a secondary decomposition or alteration of what was formerly sulphurets, but have been precipitated as carbonates from an acid-solution which carried them from the depths below ”

In speaking of vertical lead-bearing veins in the limestone at a higher horizon than the copper-deposits, he says §

“In depth the lead-carbonates have invariably given out, and what ore is found

* H. Van F. Furman, *Proc. Colo. Sci. Soc.*, Jan., 1900.

† *Trans.*, xv., 25

‡ *Op. cit.*, 55.

§ *Op. cit.*, 59.

in depth in these vertical fissures is copper-ore. It is probable that these veins are spurs of the great bed-veins opened in the Queen, Prince and other mines."

Of the veins in porphyry in the same district, he says.*

"The oxidized copper-ore, as usual in siliceous rocks, changed into copper-glance but little below the outcrop. At an inconsiderable depth it became very much impoverished and pinched. In fact, here as elsewhere, the copper-glance appears to be not a true ore at all, but a product of decomposition and of secondary origin derived from the leaching of the vein above and subsequent concentration at a lower point. To those conversant with the beautiful process of kernel roasting, the presence of a zone of copper-glance presents a similar phenomenon on the grand scale of nature's work. The oxidation of pyritous croppings is but a roasting carried out during ages by the combined action of air and moisture."

In his recent paper on the Copper Queen mine,† Dr James Douglas gives it as his opinion that the deposits in limestone were "originally more or less compact iron pyrites carrying a small percentage of copper," and that during the progress of alteration "the copper by a process of segregation, akin to crystallization, was concentrated and collected into areas of limited size, thus constituting the comparatively small bodies of oxidized ores which are disseminated irregularly through the very large masses of ledge-matter." More pertinent to the question under discussion, however, is his description of the great mass of compact pyrites extending from the 200 to the 400-foot level on which "a string of stopes, nearly 500 feet in length, has been opened," which is decomposed on the exterior and surrounded by a zone of altered limestone and of aluminous matter, generally barren of copper. "Roughly speaking," he says, "the mass is enveloped in a shell of oxysulphide, and streaks of similar black copper-ore of good grade intersect it; but the core consists of compact bisulphide of iron very lean in copper." Oxidized ores extend to a considerable depth below this mass, for which he offers the same explanation that I do, namely, that the pyrite mass was more dense and impermeable than the rock mass below, and that the oxidizing waters penetrated it but slowly.

I have given priority to the observations of these gentlemen where they confirm my own, because they are the result of much more extended studies than it was possible for me to make in the limited time at my command.

* *Op cit*, 57

† *Trans*, xxix, pp 511, 531, 534

Of the four great copper-producing districts of Arizona, three, namely, Bisbee, Globe and Clifton-Morenci, resemble each other, in that the deposits occur in a region of limestones and intrusive eruptive-rocks and under climatic conditions of extreme aridity. The fourth, the United Verde mine, near Prescott, which has a somewhat greater precipitation, owing to its vicinity to the Plateau region of northeast Arizona, is in a vertical-shear zone of old (probably Algonkian) slates and intruded dioritic rocks, the neighboring limestones being of later age, unconformably superposed, and apparently having no connection with the deposits. The physical conditions there more nearly resemble those of Butte than at either of the other localities, and an underground study would probably have been most instructive. Unfortunately, the policy of the exclusion of visitors pursued by the owner was strictly enforced in my case, and I could only determine that rich sulphides do occur beneath the gossan.

At Bisbee the Copper Queen deposits, which include all that were actively worked at the time of my visit, are in flat-lying limestones which are underlain by quartzites and have not been developed to any great vertical depth, so that I can only confirm the evidence already presented that there have evidently been considerable migrations in the ore since they were originally deposited, and that their original form was probably low-grade pyritous masses of great size, the ores at present worked, both oxides and sulphides, being concentrations produced by these migrations.

At Globe, the principal copper-deposits lie along a great east and west fault-plane, through the displacement of which limestones have been brought down in juxtaposition to underlying quartzites and intruded sheets of dioritic rock. Some isolated bodies of ore are said to occur in the dioritic rocks, and, according to Wendt, these are mostly sulphides. Those which I saw, and which constitute the main mass of the copper-ore, are in the limestones on the south of the fault. The ores thus far opened have been mainly carbonates and oxides, but in the lower levels, 400 to 500 feet below the surface, the latter are passing into the dull earthy-looking glance, called "black sulphide," which is the characteristic alteration product at the line between oxides and sulphides. The original ore-deposi-

tion appears to have occurred mainly along the great fault-fissure, and secondary migrations to have taken place along subordinate fractures either nearly parallel or at right angles to it, which evidently formed channels for the surface-waters. It was noticeable that here, as Dr. Douglas has stated to be the case at Bisbee, cuprite and native copper are more common in the lower part of the oxidized zone, and the carbonates nearer the surface.

In the Clifton-Morenci district, near the borders of New Mexico, the area of mineralization is much larger and the geological conditions are more complicated. A series of quartzites and limestones resting on granite have been extensively cut through by igneous intrusions of both basic- and acid-eruptives, and since broken by a complicated system of faults. The original mineralization apparently took place along shear-zones or faults, the ore is found both in the eruptive-rocks and in a certain horizon of limestone.

The mines were long worked for the rich carbonate ores near the surface which are now in great measure exhausted, so that at present the most common ore is the so-called "black sulphuret," the dull-black glance above mentioned. This, I found, as in Globe, immediately below the ores of cuprite and native-copper. In the larger veins, spots of pyrite can be detected within the glance which constitutes the rich ore. In the porphyry adjoining is a net-work of narrow veins or joints filled with glance. This constitutes the lower grade, or concentrating-ore which is remarkably free from other metals than copper, and appears to have been formed by migration from a main body. Below the ore-bearing zone, the limestones are impregnated with practically barren pyrites, and the porphyry below the ore-bearing zone has its joints also filled with pyrites. In some cases the direct passage of the glance into the low-grade pyrites could be observed.

The Coronado mines, famous in the early days, but now abandoned, exhibited a vertical ore-body within a dike of quartz-porphyry which cuts through the basal granite. Of this ore-body Wendt says *

"Whenever the copper-glance in the Coronado mines has been followed down,

* *Trans*, xv., 38.

it disappears at a depth of 150 or 200 feet from the surface, and either the vein becomes barren, or the glance is replaced by yellow sulphurets sparingly disseminated through the gangue "

In New Mexico, the Santa Rita mine is famous as having been worked at a profit early in the past century under Mexican rule. It lies about 15 miles east of Silver City, N. M., the ore is found in a white quartz-porphyry which was evidently once covered by horizontally bedded limestones that still lie round the rim of the shallow basin where it occurs. The richest ores have been removed from the surface, and, as the underground workings were inaccessible, my hastily-formed opinion of the deposits would not be of much value, except that I came to it fresh from an examination of others in which many analogous conditions occur. As at present seen, the porphyry at the surface is impregnated with a thin coating of azurite on joint-faces and in spots through the mass of the rock. At some depth below the surface cuprite and native-copper are associated together, largely as the filling of narrow joint-seams, and pass still lower down into the dull copper-glance similarly distributed. From the evidence of the dumps, pyrite occurs at still greater depths, but in quite limited quantity.

My judgment was, that most of this ore had been formed by leaching down from the low-grade pyritous body in the limestones which once covered the porphyry. Considerable bodies of hematite-ore, evidently the result of oxidation-in-place of bodies of pyrite, are frequent in the limestones of this region; and, in the Hanover mine, it is said that copper-ores have been found in the pyrite immediately under the hematite.

In Bingham Cañon, Utah, where the climatic conditions are intermediate between those of Butte and of Arizona, old mines, which were once worked for the value of their pyritous ores in lead and silver, are now being reopened, because the same pyrite-bodies are found in depth to contain enough copper to pay for working under present economic conditions. The ores occur as a replacement of certain limestone-beds in a great series of quartzites that are cut by intrusive bodies of porphyry and have subsequently been faulted.

In the Highland Boy mine, which I visited last summer, I found a large body of pyrite replacing limestone in the immediate vicinity of a body of quartz-porphyry. Portions of this

body, which were compact and unaltered, were too lean to work. Along certain lines of post-mineral fracturing or faulting, however, the mass was found to be altered and constituted an ore that was said to average 8 per cent. in copper. In those places where the enrichment was visible to the eye, a little copper-glance, with the dull earthy appearance that is characteristic of the recently formed secondary mineral, could be distinguished.

Western Silver Deposits.—Instances of probable secondary enrichment of silver-bearing deposits from my earlier examinations, now occur to me as I look back, but as they were not examined critically with a view to this explanation of their formation, I place less weight upon them.

Most famous, in view of the enormous values taken from them, are the rich silver-bodies of the Mollie Gibson and Smuggler mines of Aspen, Colo., but, in their case, there is sufficient organic matter present to explain the reduction of the oxidized solutions to sulphides.* They occur along a vertical fault formed since the original mineralization of the district, and consist of great masses of polybasite and pink barite, which, in places, have been further reduced to native-silver. On one wall of the ore-body is the limestone, of which it is a replacement, and on the other, a black bituminous shale.

In the San Juan region of Colorado, there is a very strong belief held by some of the more experienced and thoughtful mining engineers, that the rich silver-minerals in their veins, such as ruby- and brittle-silver, are the result of secondary enrichment by descending waters. The most notable instance presented (which, however, I have not yet had opportunity of verifying by personal observation) is that of the famous Smuggler-Union vein, which has been opened for some four miles on the strike, and in places to a depth of nearly 1,000 feet. The main vein has a width of several feet of comparatively low-grade concentrating-ore, while on the foot-wall is a streak a few inches thick of rich "shipping" ore, which carries the rich silver-minerals. The main vein has been displaced about 50 feet by the Pandora vein, which crosses it at right angles and carries gold-values, though not in paying quantity.† Accord-

* *U S Geol. Sur.*, Mon. xxxi, Aspen Mg. Dist, p. 183

† *U S Geol. Sur.*, 18th Ann. Rep., Pt. III, p. 834

ing to my informants, the foot-wall streak is not sensibly affected by the faulting, and they reason that it is a plane of recent movement, on which the silver-minerals have been concentrated by a secondary migration from the main vein.

In several important veins in the San Juan region, I observed secondary or post-mineral fractures parallel, and more or less coincident, with the plane of the vein, but no detailed studies have yet been made that would determine whether there has been an enrichment of the minerals, or not.

In unpublished notes on the once famous, but now abandoned, Yankee Girl mine, in the Red Mountain district of the same region, I find mention of a phenomenon which then appeared unexplainable, but which it now appears might be accounted for on the theory of secondary enrichment. In the upper levels, the ores, down to about 200 feet from the surface, were mainly silver and lead, galena and pyrite being the principal minerals. Below this zone, the ore is mainly composed of stromeyerite, bornite, chalcocite, with some gray-copper and barite, yielding about 30 per cent of copper, and little or no lead. In depths below 600 or 700 feet, the ore in this and adjoining mines is said to have gradually turned into a low grade pyritous ore, which was of too low grade to work at a profit, and caused the mines to be closed down. The ores in the copper-bearing zone had been exceptionally rich, carrying several thousand ounces of silver to the ton in carload lots. The waters in this region, both mine-waters and spring-waters, are unusually acid, the latter forming abundant deposits of limonite, while the former rapidly corrode any metallic iron-materials, such as water pipes, that are exposed to their action.

The most definite instances of secondary enrichment of silver sulphides are, however, those described by Weed, in the mines of Nehart, Mont.* There the veins have suffered later fracturing and secondary enrichment of the zone at or below the water-level, with the deposition of silver sulphides "as crusts or crystals lining cavities, or as films or thin coatings along fractures of the primary ore." The primary minerals are galena, blende and pyrite; the secondary sulphides are polybasite, ruby-silver, more rarely a pure transparent blende. Under the microscope

* *U S Geol Sur*, 21st Ann. Rep., Pt. iii "The Geology of the Little Belt Mountains," by W. H. Weed, p 421

galena is seen altering to a spongy polybasite. Polybasite and pyrrargyrite are seen as crystalline aggregates and crusts on all other minerals, but in no case coated by other minerals. The immediate products of superficial alteration, the gossan, are largely removed and make up a zone at most only a few feet thick. Beneath this is an irregular accumulation of sooty black ore, consisting of manganese and silver sulphide. Where the vein is well-defined the secondary antimonial sulphides occur below, at first, in considerable abundance, but deeper down, only in crevices or fissures partly or wholly lining filled fractures, so that they become less and less abundant in going down on the vein.

Eastern Examples —In his description of the lead- and zinc-deposits of the Mississippi,* W. P. Jenney notes interesting instances of deposition by descending-solutions below the zone of oxidation.

Among minerals of secondary deposition he enumerates "blende, galena, chalcopryite and greenockite, produced by alteration from the primary ores in the zone of oxidation in the upper part of the ore-bodies, and re-formed as sulphides by the reducing action of organic-matter in the deeper levels."

Iles† and Robertson‡ have also described secondary deposits of zinc-sulphide which are assumed by them to have been deposited from a sulphate solution through the agency of sulphuretted hydrogen.

In the Southern Appalachian region are many copper-deposits which show excellent instances of secondary enrichment through the agency of mineralizing waters. Most of these have recently been examined by Mr. Weed,§ and, as detailed descriptions of them will be found in his paper on "Types of Copper-Deposits in the Southern United States," presented at this meeting, only a brief mention of the salient points need be made here.

Best known are the deposits of Ducktown in the extreme southeast corner of Tennessee, which have become classic in the literature of ore-deposits for their black copper-ores which

* *Trans.*, xxii, 199.

† *Eng and Min Jour*, vol xlix, 1890, p 499

‡ *Am Jour Sci*, 3d series, vol. xl, p 160

§ *Bull Geol Soc Amer*, vol xi, pp 179-206

form a narrow band between the gossan and the unaltered pyritous ore beneath. The gossan-ores are immense masses of porous iron-oxide which are so free from impurities as to be used in large quantities in the blast-furnaces of Tennessee and Virginia. The original ore is an irregular mixture of pyrrhotite and chalcopyrite, quite massive and free from vertical fracturing. The comparatively thin zone of black ore has been considered to be a mixture of black oxide and sulphuret of copper; but chemical examination of the specimens brought in by Mr. Weed and those in the National Museum show only copper-glance and no tenorite. The ore is impregnated with copper sulphate, showing that the process of concentration is still going on, and recently-formed amorphous black sulphuret is found in clefts in the upper surface of the pyrrhotite.

When the black ores were first developed many curious speculations were current as to their origin; but Whitney⁺ early recognized their true source, as is most evident in his reply to Tuomey in 1855, where he ascribes these rich sulphides to an enrichment of the original ore through the decomposition of the zone above (now gossan).[†]

Sterry Hunt[‡] makes allusion to this, and similar deposits, at Ore Knob, N. C., and in Carroll county, Va., as owing "their origin to the reduction, in some imperfectly explained way, of the sulphates formerly generated by oxidation in the upper portion of the lodes," and Olcott[§] confirms his view as to the Ore Knob deposit. In all these cases, however, the enrichment is assumed to have taken place at or above the water-level, and there is no question of its extending to any considerable distance below it.

In the Union Copper Company's mine at Gold Hill, N. C., as reported by Mr. Weed, the ore-body is fractured by vertical planes which penetrate to some depths below the oxide zone. There are here no such great masses of pyritous ore as at Ducktown, the primary ore being vein-quartz carrying a small amount of chalcopyrite. Owing to the vertical fractures the lower limits of the brown oxidized ore are very irregular, extending in places down to 180 feet or more below the surface

⁺ *Metallic Wealth of the United States*, p 322.

[†] *Amer. Jour Sci.*, 2d series, vol xx, p 53

[‡] *Trans*, ii, 127

[§] *Trans*, iii., 392

and half that distance into solid unaltered quartz-ore. The surface-ores were originally worked for gold, but the increase of copper with depth interfered with amalgamation.

The workings now extend to a depth of over 250 feet. In the main part of the vein are rich masses of chalcopyrite in quartz which, when altered, change directly into chalcocite, the latter is often surrounded by a film of cuprite, which, in turn, changes to fibrous malachite along cracks in the quartz. Where the alteration has proceeded further, specimens are found showing copper-glance coated with crystalline cuprite and native silver; others show crystalline glance passing directly into native copper, which forms a thin felty covering up to a quarter of an inch thick. Nearer the oxide zone, a sooty black mass is often found directly replacing the chalcopyrite.

Specimens from the Blue Wing mine in the Virgilia district on the borders of Virginia and North Carolina, taken from below the oxide zone, show bornite surrounded by a shell of dull glance with iron oxide outside. Other specimens from below the water-level show bornite altered to chalcocite, while the iron is concentrated in the form of nests of specular iron in the quartz. These ores extend to the present limits of the workings 300 feet below the surface. That they will pass, like those of Gold Hill, into chalcopyrite in depth, cannot yet be predicated with certainty.

Foreign Authorities.—Although it was the Austrian geologist, Posepny, already cited, who most strongly emphasized the distinction between the results of the action of surface- and deep-seated waters, European geologists seem to have been, as a rule, slower to recognize this distinction in their practice than American mining geologists, whose views are generally gathered from a wider field of observation.

The brilliant French writer, DeLaunay,* has been cited by Mr. Weed as one who seems to have conceived the idea that the enrichment of sulphides by descending surface-waters has been an important element in the formation of ore-deposits, and

*I. On the importance of deposits by magmatic inclusion and segregation in a classification of ore-deposits.

II. On the part played by the phenomena of superficial alteration and the renewal of movement (migrations) in the formation of ore-deposits.—*Ann. des Mines*, 9th series, xii, 1897, p. 119-228.

indeed the title of his most recent theoretical discussion of the question gives ground for this supposition.

A careful reading of this and his other papers, however, leads rather to the conclusion that the secondary migrations he contemplated were confined to the zone above the groundwater-level, or oxidized zone, in which sulphides have always been known to occur. The novelty of his view would appear to be that they are not necessarily residual masses of sulphides that have not been completely oxidized, but that in many cases they result from an actual transference of material and a re-deposition as sulphides. Thus, in closing his discussion on the origin of copper and ore-deposits,* he says

“What is the origin of the modifications which have been noted in a general way in the upper part of a vein, modifications undoubtedly connected with nearness to the surface, and which disappear in depth? Is it possible that these modifications have sometimes been produced contemporaneously with the filling of the vein, or are they always, as is incontestably the case in many instances, the result of much later action, especially of the introduction of surface-waters down to a certain level called hydrostatic?”

In his later paper, after describing the succession of minerals found in the silver-deposits of Mexico and South America as an upper zone of chlorides and native metals, and below this a bonanza-zone, where the silver and copper “coming in part from the surface” are concentrated by a sort of cementation as rich sulphides, etc. (both, however, being above the water-level), he speaks of the chemical processes that have probably gone on, as follows

“The atmospheric-waters reached the deposit by descending and filtering down slowly along the plane of the vein to ascend again to the surface only after a circuit that is more or less long and complex. It results that the elements dissolved are not absolutely lost to the vein, but, on the contrary, a great part of them are only slightly displaced from above downward, and are re-precipitated in depth in contact with unaltered sulphides in the form of insoluble sulphides. This secondary phenomenon, which is particularly marked for copper and silver, often brings about a special concentration of these two metals at a certain distance below the surface, so that below the oxides and carbonates that characterize the actual outcrop is found a very rich zone, or, as the miners of the New World express it, a bonanza, in which copper forms gray-copper, glance, bornite, etc., while silver separates as argentite, brittle-silver and ruby silver.”

European Deposits.—The great pyrite-deposits of Rio Tinto,

* *Gîtes Minéraux et Métallifères*, Paris, 1893, vol. II, p. 232.

Tharsis, etc., in the Huelva provinces of southern Spain, are enormous bodies, analogous in geological conditions to those of Ducktown, but of even greater volume. The gossan, which extends down to a depth of 130 to 150 feet, consists mainly of iron oxide, with 50 to 55 per cent. iron, a little sulphur and arsenic, and only a trace of copper. Between this and the solid pyrite below is a very regularly distributed zone of earthy, porous material, from a few inches to a foot in thickness, carrying an average value of about \$35.00 per ton in gold and silver. These values it is assumed by Vogt,* who has last written upon the region, have been brought down in solution by ferric sulphate which, in contact with the underlying pyrite, has been reduced to ferrous sulphate, with precipitation of the gold and silver. It is in the pyrite-mass below the "iron hat" that the copper-values are found, and these gradually decrease with depth from 4 to 5 per cent. in the upper 100 to 200 feet to $1\frac{1}{2}$ per cent. at the depth of 900 feet—varying somewhat with local conditions. The geologists who have studied the region account for this decrease by assuming that, during the oxidation of the gossan, the original copper-contents were leached down and re-precipitated in recent fractures and clefths in the pyrite mass, thus enriching its upper part. Says Vogt

"In point of fact we find such minerals—copper-glance, bornite and chalcopyrite, sometimes with galena, zinc-blende and gray-copper, and, as a rule, accompanied by quartz—very often in clefths and cracks in pyrite, and these minerals are, without doubt, of younger (secondary) formation. At times these clefths are so large that they can be separately mined, thus, the old Roman mining was done chiefly on these richer clefths within the poorer mass of pyrite. Most commonly, however, they are quite small and constitute a strongly branching network in the normal pyrite-mass, and that the copper-content of these secondary minerals is derived from the weathered, superficial mass is shown quite simply in the fact that these veins are most common in the zone immediately under the 'iron hat'. They extend downward something like a hundred meters or more, and then commences the solid pyrite-mass, little fissured and comparatively barren of copper."

He also mentions a decrease of copper-contents with depth in the great vertical pyrite-deposits of Vigsnas, in Norway, and Fahlun, in Sweden, of which the former has been worked to a depth of 735 meters and the latter to 350 meters.

At Monte Catini, in Italy, the rich copper-ore occurs in

* *Zeitschr. Prakt. Geol.*, July, 1899, pp. 249, 250

masses sometimes of several cubic metres in size with an arrangement of concentric zones which grow successively richer in copper towards the periphery. These masses are sometimes isolated; sometimes connected with metalliferous veins. Balls of glance occur sometimes the size of a man's head. The larger masses consist of chalcopyrite at the center, surrounded first, by bornite, and then on the outside by chalcocite, which sometimes passes into native-copper. These rich masses occur in a zone of recent movement which is easily penetrable by surface-waters. In depth the rich sulphides cease and the ore consists of chalcopyrite and pyrite, the latter becoming more and more predominant with depth.

There are many other European examples which would doubtless show evidence of secondary enrichment, if examined with that question in view. In the great zinc-, lead- and silver-deposits of Laurium, in Greece, for instance, it seems that this process might explain some of the phenomena about which there has been so much difference of opinion among those that have examined them.

Deposits in Arid Regions —De Launay, who has studied the literature of Mexican and South American mines very extensively, makes the following general statement as to the average conditions of the silver-ores in those countries from the surface downwards:

"Near the surface the silver in the veins is in the native state, with chlorides, bromides, iodides, etc., associated with oxides of iron, manganese and often of copper, if the gangue is siliceous, it shows a honeycomb aspect, resulting from the removal of the sulphides which it formerly held, frequently red and gray clays are associated with it. These ores are the *pacos, cascayos, colorados*, etc., of the Spanish-American miners, which are designated by the general term *metales calidos* (free milling ores), but whose tenor in silver is often small compared to the rest of the deposit.

"Lower down, at about 80 to 150 meters, appears the bonanza-zone of the Mexicans, where by a sort of phenomenon of cementation is concentrated the silver, coming in part from the surface (often with the copper, if this is abundant in the deposit). The silver is here in the state of sulphide (Ag_2S), the copper as chalcocite, gray-copper (itself often argentiferous) and bornite, iron is wanting or is in the form of oxide; lead, not abundant, is mostly in the state of carbonate.

"Finally, when one passes below the hydrostatic level, which is rarely lower than 400 or 500 meters, one finds the complex vein-filling of sulphides, antimonides and arsenides, which in their primitive form extend indefinitely in depth, that is, one has, in proportions varying with different deposits, galena, more or less argentiferous, iron and copper pyrites, arsenopyrite, blende, etc., with less abundant silver-minerals."

My personal observations in these countries have been very limited, being confined to a few weeks' visit in Peru and the State of Chihuahua, Mexico, respectively. In Peru, I saw a dull-black copper-glance, brought from the famous Cerro de Pasco mining-district, where silver-mining has been extensively carried on for centuries. This ore is said to be found wherever the workings have been carried down below the water-level, and is estimated to constitute a zone of great extent and value beneath all the old workings. It is evidently a concentration by leaching of the small amount of copper that was disseminated through the now oxidized ores above.

In Chihuahua, I had no opportunity to examine the silver-deposits below the water-level, but in the middle levels of the mines, at 200 to 300 feet below the surface, oxidized and unaltered sulphide ore-bodies were not infrequently found side by side, so to speak, on the same level. The former, generally in a foot-wall streak, constitute the *colorado* ores of the Mexican miners, and carry rich silver-minerals in a red clayey material that contains rolled fragments of quartz and ore, and is evidently on a plane of movement subsequent to the mineralization. The latter, which consist of pyrite, galena and blende in a dense hard matrix, occur in greater bulk than the richer ores, and apparently owe their escape from oxidation to their impenetrability to surface-waters. The sulphide is so much lower in grade than the *colorado* ore, that it was generally left by the early miners, and now constitutes a concentrating-ore. Evidently the foot-wall streak, which often opens out into great "bonanzas," was enriched by the leaching of such parts of the other ore as had been thoroughly decomposed.

In Australia, the arid climate of which presents similar conditions to those found in Arizona, Mexico and South America, we would expect, as in the latter regions, to find abundant evidence of secondary alteration of ore-deposits. In point of fact, the descriptions of many of the important mines of that region make mention of phenomena which seem to be most readily explainable on this theory, although, until they have been examined with this end in view, one cannot be sure how far all the evidence will support it. In the famous Broken Hill lode, as described by Jaquet in the memoirs of the Geological Sur-

vey of New South Wales, certain occurrences are definitely described by him as secondary sulphides.* The primary sulphide-ore is an intimate mixture of argentiferous galena and zinc-blende, with quartz, garnet and feldspar, and pyrite, chalcopyrite, arsenopyrite, wulfenite and fluorite as accessory constituents. These ores contain on an average 5 to 36 oz. of silver per ton, 7 to 50 per cent of lead, and 14 to 30 per cent of zinc. Mr Jaquet says

"Sulphide-ore, secondary, occurs as a thin layer, varying in thickness from 3 inches to 6 feet, which coats the ordinary sulphides at all points where dry ore, rich in silver, comes in contact with them. Resembling soot somewhat in appearance, it has been named 'sooty sulphide-ore' by the miners. It is, without doubt, ordinary sulphide ore altered and enriched by contact with dry ores."

These enriched ores carry up to 250 oz. silver per ton and 12 per cent of copper. The dry silver-ores are the antimonial and arsenical sulphides of silver, polybasite, stromeyerite, dyscrasite, proustite, pyrargyrite, stephanite, etc., which occur in the lower part of the kaolin-ore that forms the bulk of the oxidized zone in the locality described, and carries oxidized minerals of iron, manganese, lead and copper. This, also, is of much lower grade than the enriched sulphide. It is very evident, therefore, that in the process of alteration by surface-agencies the oxidation products—especially the silver- and copper-combinations—have been leached down and redeposited as sulphides, and are most abundant in contact with the original sulphides of the deposit.

It does not appear from the descriptions that the enrichment has extended to any considerable distance below the contact-zone of altered with relatively unaltered material. This may be due to the absence of later fractures which would admit the descending solution; or it may be that enrichments do exist which have not yet been detected through want of systematic search.

In the neighboring Broken Hill Consols mine, as described by Mr George Smith,† there is evidence of still more extensive secondary enrichment of sulphides, the silver-minerals being mainly in the rather rare and unusually rich forms of stromeyerite, dyscrasite, fahlerz and antimonial silver chloride.

* *Mem. Geol. Sur., New South Wales, Geology*, No. 5, Sydney, 1894, p. 88. See also *Zeitschr. Prakt. Geol.*, vol v, p. 95. 1897

† *Trans.*, xxvi, 69, 71, 73

Although occurring in the same country rocks as the main Broken Hill deposit, instead of being, as in that case, in the form known as "saddle reefs," which conform with the schistosity and are of great size, they are found only in comparatively narrow veins which distinctly cross the schistosity. The vein is mineralized only at the intersection of what is known as cross-veins, and, of the rich silver-minerals mentioned above, some "have not been met with in the lower workings, though each has been found at some distance below the water-level;" while those that are found at greater depth occur there in smaller quantities and "have been found to assume a distinct track and are evidently the continuation of the larger deposits worked in the upper levels." The so-called cross-veins are described as "a succession of rock-joints formed along a line of weakness and enlarged in places by a process of removal and replacement." The more important one, which is figured (p. 73), falls vertically on the lode which has a shallow dip near the surface, and immediately below it in the main vein is an accumulation of stromeyerite, dyscrasite and more or less oxidized material impregnated with silver chloride. The cross-veins carry in some cases blende and galena, in others only pyrite.

While Mr Smith has recourse to secondary concentration for the enrichment of the oxidized zone, it does not seem to have occurred to him that the concentrations of rich mineral below this zone might also have been produced by solutions along the main fissure from the cross-veins. He brings forward a theory of electro-magnetic currents to account for the precipitation of the minerals at these intersections

It is always unsafe to theorize on the observations of others; but in the present case, it seems legitimate to offer the suggestion that, even admitting the possibility of electric action as a stimulant to the chemical reactions, it is necessary to predicate previous conditions which will render the reactions possible. In the case of these cross-veins, as in those of the indicators of Ballarat, and the similar fahlbands of Norway, which are all zones of relatively barren pyritiferous materials crossing the ore-bearing veins, it seems, in a general way, that reactions between salts of the metals and their sulphides have been the underlying cause of the concentration of the more valuable metals

at or near the intersection. There will have been a great number of differing conditions in such districts, or groups of deposits, and it does not seem absolutely necessary that we should have recourse to descending solutions for the salts of the metals in every case; they may have been contained in ascending solutions. An instance where it seems probable that there has been enrichment from ascending salt-solutions is the Geyser mine at Silver Cliff, Colorado,* where, in a narrow vein at 2000 feet in depth, is an unusually rich and very recent-looking body of sulphides of silver, lead, zinc and copper. The ascending waters which issue from the parallel and adjoining fissures are highly charged with carbonic acid, and carry, apparently in the form of carbonates, small amounts of the metals found in the veins. Whatever may have been the original form in which the metallic minerals were brought to this deposit, it seems evident that at the present day they must be coming in as carbonates and be deposited as sulphides in contact with the already existing sulphides, thus enriching the latter.

SUMMARY

From the foregoing geological evidence, which could be doubtless very much enlarged, it appears to be fairly well established.

1. That descending waters not only cause migrations, or transference and reconcentration, of the alteration products of the original vein-materials in oxidized form, producing in one place an enrichment, and in another possibly an impoverishment of the original deposit, but that in their further downward course the oxidized forms are frequently reduced and re-deposited as sulphides, thereby producing a sulphide enrichment of the original vein-materials.

2. That this secondary enrichment of sulphides is not necessarily a reduction in the presence of organic matter, but is frequent where no organic matter can be supposed to be present; it occurs mainly in contact with the original sulphides of the deposits, and is, presumably, a result of chemical reaction between these sulphides and the materials brought down in solution by the descending waters.

* *U S Geol Surv., 17th Ann Rep, Part II., p. 456*

3 That while this re-deposition of sulphides in many cases appears to commence at or near the groundwater-level, it does not appear to have a necessary connection with that level, and may under favorable conditions extend below that level for a distance as yet undetermined, the most important favoring conditions appearing to be recent or post-mineral fractures, which have admitted a relatively free and uninterrupted descent of these waters

In endeavoring to trace back the processes by which the results have been brought about, it is important to bear in mind the physical changes that may be assumed to have taken place during the time that has elapsed since a given ore-deposit was originally formed and before it reached the condition in which it is found at the present day. These changes necessarily vary with each mining region or district, being in some cases very considerable, in others relatively slight. They may be classed under two general categories

First, the rock shatterings resulting from dynamic force connected with earth-movements or eruptive action. These have opened channels for the entrance of surface-waters within the rock-mass and thereby extended the areas to which the chemical actions produced by the latter may have extended

Second, the erosion or denudation to which the region has been subjected, and which has gradually worn down the original surface to its present configuration. As a result of this wearing down the lower parts of an ore-deposit have been continually approaching the surface, and in no case, probably, is what was originally the superficial portion of an ore-deposit still in existence. The amount of the wearing away is not always determinable, but it may have been very large, thus, at Leadville, I estimated that in round numbers a thickness of about 10,000 feet of rocks had been worn away in order to bring the ore-bodies at present exposed to the surface.

In the Butte district, where there are no stratified rocks, there exists no criterion by which to estimate accurately the amount of denudation, but the readily disintegrable character of the granite country-rock and the faulting to which I have already alluded show that it must have been very considerable. There the ore-deposits occurring along nearly vertical fissures, and the later shattering having produced extraordinarily

abundant secondary fissures nearly coincident with the earlier ones, the conditions were unusually favorable for an abundant leaching down of the material taken up in solution by the surface-waters. As the surface gradually lowered we may conceive that the insoluble materials were carried off mechanically, of the soluble minerals, however, but a relatively small proportion would have been removed by the actual surface run-off. The greater portion would have been carried back to lower levels before they came near enough to the actual surface to be taken up in the run-off.

It will aid our conception to divide the veins theoretically into three horizontal zones. The upper- or surface-zone, that which immediately adjoins the present surface, is necessarily the zone of highest and most recent oxidation. Any sulphides found in it will simply be residual masses which, for some reason, the oxidation has not completely penetrated. The changes which have taken place in this zone will have been mainly of removal, rarely of addition, and any enrichment that will have come about in this zone will have been, as a rule, differential, resulting from the greater proportion of valueless or base metals removed.

The second or intermediate-zone may be called the zone of oxide-enrichment. In this, the less soluble or more readily precipitable metals which have been brought down from the zone above, are found as carbonates or oxides, or in some cases as native-metals.

The third zone may be called the zone of sulphide-enrichment, in which the materials brought down in solution, and not deposited in the zone next above, are deposited as sulphides (also as sulph-arsenides and sulph-antimonides) or in some cases as native-metals in contact with the original sulphides of the deposit.

The presence of organic matter would hasten the reduction to sulphide, and might cause the deposition of the latter, under favorable conditions, even at the surface, but it should be considered as an accidental, rather than an essential occurrence.

These zones are, as has been said, a theoretical conception; in practice they are rarely well-defined, and in many cases one or more may be wanting. One will run into the other, and, as denudation progresses, a lower zone is slowly changing to the

one next above it: thus, as time goes on, it will be a constantly richer zone that rises to the surface to be oxidized, and has part of its oxidation products carried back and re-deposited either as oxides or sulphides. Hence, other things being equal, the longer a deposit has been subjected to denudation the greater will be the enrichment below the surface-zone. The rate of denudation may also have influence upon the amount of enrichment, for it can be conceived that the surface-rocks may be so readily disintegrable and the rate of erosion under favoring climatic conditions may be so rapid, that the surface-removal of the oxidized material, both mechanical and chemical, may proceed so much faster than the downward seepage along the plane of the ore-deposit, that little or no enrichment of the interior portion of the deposit may have taken place.

Such a rapid denudation may be conceived to have taken place on exposed points during the ice-invasion of the glacial period, at which time, moreover, under the low surface-temperatures chemical decomposition would have been relatively sluggish. In arid regions, on the other hand, where the great heat would render chemical decomposition more energetic, and where there has been not only no ice-action, but also comparatively little erosion by water to wear down the surface, we should expect the zone of oxide-enrichment to extend down to great depths, but if the aridity were so great that there was very little water percolating through the rocks in depth, there might be but little sulphide-enrichment.

Chemical Processes Involved—I do not feel prepared to discuss in detail the chemical processes that are involved in the changes which are shown to have taken place by the above quoted observations. They necessarily vary from one deposit to another under the varying mineralogical and physical conditions that prevail in each place. Moreover, the chemical reactions that are suggested by previous investigations should be tested experimentally before any one can state with any degree of confidence what the succession of chemical processes in a given case has been, for these investigations have generally been conducted with another object in view, or with a different conception of the actual conditions in nature.

Mr. Weed, in his paper already cited, has given quite full quotations from all the authorities that bear upon this subject,

and I shall, therefore, not repeat them, but only give a brief general statement of the main processes that may be supposed to have contributed to the mineralogical conditions that are found in the ore-deposits cited above, laying more stress on the natural occurrences that illustrate the actual changes.

The most common sulphide-minerals in original ore-deposits are the iron sulphides, pyrite, marcasite, pyrrhotite, chalcopyrite and arsenopyrite, and next to these, galena, zinc-blende and various copper sulphides. While there is a great variety of other metallic compounds in ore-deposits, yet in most deposits the greater bulk is so far formed by one or more of the above minerals that the chemical changes will be largely governed by the reactions to which these appear to be subject. Of these sulphides marcasite is the most readily decomposed, while pyrite, if occurring by itself in pure crystals, often proves very resistant to alteration. Where there are mixed sulphides, however, the oxidation is observed to proceed more rapidly and all are readily attacked.

The actual changes observed by me in a great body of pyrite carrying galena in a limestone country-rock, which had undergone partial decomposition from the periphery inwards, are as follows * The original fresh pyrite or marcasite crystals are first disintegrated and slightly pitted on the surface, then changed to melanterite or hydrated ferrous sulphate and the galena becomes anglesite. In the outer or more fully oxidized zone the iron-vitriol has changed in part to yellow basic sulphate; in part to limonite with a separation of native sulphur.

The theoretical changes that are assumed to take place by the action of waters carrying oxygen or oxidizing agents are. first, an alteration of the iron sulphide to ferrous sulphate with the formation of sulphuretted hydrogen and sulphur which may have oxidized to sulphuric or sulphurous acid. By further oxidation the ferrous sulphate will become, in part at least, ferric sulphate, and this in its turn will react upon the remaining ferrous sulphate, or upon the sulphides, and form more ferrous sulphate or sulphates of the other metals which are present. By this cycle of reactions a supply of both ferric and ferrous sulphates would seem to be provided in the oxidized zone, but

* *Proc. Colo. Sci. Soc.*, vol. 11, p. 104.

the extending downwards of the ferric salts would decrease as the supply of oxygen in the waters became less abundant.

It may be assumed that the sulphates of the metals thus formed would be transported for greater or less distances, generally in proportion to their solubility, the iron sulphates being the most soluble; next, those of copper and zinc, silver sulphate is less soluble and also more readily decomposed, while lead sulphate is extremely insoluble.

This accords with the facts generally observed in nature. Thus, from the gossan, which is generally a porous siliceous mass stained by the limonite or hematite resulting from the decomposition of part of the iron sulphate, the copper- and zinc-salts may have been more or less completely removed or transformed to less soluble carbonates and silicates. Where galena has been present in considerable amount the sulphate (anglesite) is generally found quite near the surface or forming a coating around residual masses of galena which some think it has protected from oxidation. Where carbonate of lime is present, as in limestone deposits, it is transformed to the carbonate (cerussite) which is more soluble, especially in the presence of an excess of carbonic acid, and may be transported from its original location and concentrated in bonanzas of more or less crystalline mineral. The silver sulphate formed near the surface is generally transformed to the chloride, but is not infrequently reduced to the native state. Gold probably does not form a sulphate, but when combined, as in the form of the telluride, is directly reduced to the metallic state. It is, however, to a certain extent soluble in ferric sulphide, and would in part be transported by this solution until it is precipitated by the reduction of the ferric to the ferrous condition which may occur in contact with the sulphide or with ferrous salts.

Under certain conditions ferric sulphate will decompose the metallic sulphides with the formation of ferrous salts and sulphates of the metals; possibly also with a solution of part as sulphides. Actual test has shown that it acts with great readiness on the iron sulphides, but much more slowly on silver sulphides. The action of copper sulphide has not been tested, but is probably intermediate between the two.

It would naturally be expected that the oxygen included in surface-waters would gradually be eliminated with depth, and

Lepsius* has shown by actual experimental tests of waters taken from bore-holes that there is a gradual and fairly uniform decrease of contained-oxygen in the waters with depth. The oxygen would be more rapidly exhausted in a region of active chemical action, such as an ore-deposit in process of alteration; hence it may be assumed that in each case there will be a certain depth at which, owing to the absence of free oxygen, the general tendency in the reactions which take place will be reducing rather than oxidizing, and when no organic matter is present we must look to the original sulphide minerals to furnish the necessary agents for reducing the sulphates to sulphides again, or to the native state.

The most pertinent investigations bearing upon the reactions that would take place are those undertaken by E. F. Anthon† in 1837, primarily for facilitating analytical work in the laboratory, which were continued later on the same lines by E. Schürmann,‡ for which reason they are generally known as the "Schürmann" reactions. By these it was established that in the presence of the sulphides of certain of the metals the salts of other metals would be decomposed and the metal precipitated as sulphide, indicating thus that the latter metal possesses a greater affinity for sulphur than the former, and thus the following series of the more common metals was established in the order of their affinity for sulphur Mercury, silver, copper, bismuth, cadmium, antimony, tin, lead, zinc, nickel, cobalt, iron, arsenic, thallium, and manganese. In other words, a salt of any metal in the series would be decomposed by the sulphide of any succeeding metal, and the first metal precipitated as sulphide. Thus, from silver- or copper-salts the metal would be precipitated as sulphide by lead, zinc, or iron sulphides.

Sulphuretted hydrogen is an important agent for the precipitation of metallic sulphides, and this is not infrequently found in mine-waters. It is assumed to be given off in the deposition of the various forms of pyrite, and qualitative tests in the laboratory of the Survey have shown that it is evolved in the treatment of pyritous ores by very dilute sulphuric acid, though less freely with pure pyrite than with mixed sulphides.

* *Ber d Deutsch Chem. Gesellschaft.*, vol xviii, p 2487 1885.

† *Jour f Prak Chem*, vol x, No. 6, p 353

‡ *Luebig's Ann d Chem*, vol 249, 1888, pp 326-350

Ferrous sulphate will also precipitate many of the metals from their solutions in the native state; possibly in some cases as sulphides with the formation of ferric sulphate, and it is probable that other ferrous combinations will act in a similar manner. Thus, in the mines of Kongsberg, Norway, which are remarkable for the abundance of native-silver below the water-level, Vogt* assumes, for the occurrences of the metal, as it is sometimes found in fine cracks in the country-rock and even in garnets, that it has been precipitated from its solution through the reducing action of ferrous silicates

The reaction of ferrous sulphate on a solution of silver-salt is easily tested in the laboratory. The silver is readily precipitated in the metallic state and the solution colored brown by the ferric sulphate formed. With an excess of ferrous sulphate present, as near the out-crop of ore-deposits, this might account for the separation of native-silver from silver-salts, while on the other hand with an excess of ferric oxide the silver might be carried further down in solution

In the copper-deposits, to which my studies have been more especially directed, one often finds a black sooty alteration product in pyritous ores just at the water-level which it has been the custom to call an "oxysulphuret," but which, so far as tested, has always proved to be amorphous copper-glance. It is evidently a very recent formation and it might be reasoned that it has not yet had time to become crystalline. On the other hand, chalcopyrite is by some considered to be a compound of cuprous sulphide (Cu_2S) and ferric sulphide (Fe_2S_3) as bornite is, in a similar way, considered to consist of cuprous (Cu_2S) and cupric (CuS) sulphides with ferrous sulphide (FeS). In the attack by a solution of ferric sulphide the iron molecule would first be removed, and in the case of chalcopyrite the Cu_2S might be left in the amorphous powder above noted. If, however, the attack was continued until copper sulphate was formed, this being precipitated either by sulphuretted hydrogen or in contact with unaltered sulphide, by analogy with results obtained in the laboratory the precipitated sulphide would be a black amorphous powder. Such a precipitate was obtained by A. P. Brown† by the action of powdered pyrite on a neutral

* *Jour f Prak Geol*, April, 1899, p 118

† *Proc Amer Philos Soc*, vol. xxxiii., No 145, p 240 1894.

solution of copper sulphate under pressure during his investigations, by which he proved, as he assumed, that marcasite is largely composed of the ferrous sulphide, and pyrite contains more ferric sulphide.

Bischof* states that the amorphous precipitates from solution by sulphuretted hydrogen gradually assume a metallic luster and tend to become crystalline when extremely dilute solutions are used and the reagent is passed sufficiently slowly over the precipitates. In other words, under conditions more nearly approaching those that may be assumed to exist in nature

In recent years Dr. C. Doelter has made a series of synthetic experiments in which, by treating metallic salts by sulphuretted hydrogen solutions, he has succeeded in producing in crystalline form most of the common sulphide minerals namely, pyrite, chalcopyrite, bornite, chalcocite, covellite, galena, bournonite, miargyrite, jamesonite† and pyrrhotite.‡ The experiments were conducted at moderately elevated temperatures, generally about 100° C. Such temperatures are used in the laboratory to hasten the chemical action, but it is probable that the same effects would be produced at the ordinary temperatures, such as would be found in ore-deposits, if sufficient time could be allowed. In nature it is probable that changes in temperature may have been an important factor in producing solution or precipitation of minerals, for it has been found that a mineral-salt which was taken up in solution at a given temperature is sometimes redeposited under a change in temperature.

More significant, however, than laboratory experiments, are the synthetical processes of nature, which, as shown by Daubrée and other European geologists, have been detected in the many thermal springs, where Roman metals and coins of copper and other metals have lain for centuries subjected to the action of waters containing feeble solutions of mineral sulphates. Among the minerals thus formed crystals of tetrahedrite, chalcocite, bornite, chalcopyrite and others have been recognized. At the Springs of Bourbon l'Archambault,§ the succession of mineral

* *Lehrbuch d. Chem. u. Phys. Geol.*, Second edition, Bonn, 1866, vol. iii., p. 721.

† *Zeitsch. f. Krystallogr. u. Mineral.*, vol. xi, p. 40.

‡ *Miner. u. Petrog. Mitth. v. Tschermak*, vol. vii, p. 535.

§ *Comptes Rendus*, vol. lxxx., January-June, 1875, p. 1297.

coatings around the metallic copper of the coin is the exact reverse of the series which has been noted above in copper-mines as the normal change in waters by secondary changes, namely, next the metallic-copper, first, black copper-glance; then bornite, then chalcopyrite

That the reactions necessary to produce these changes have taken place in nature in a certain regular series is, in itself, fair ground for assuming that under possible variations of conditions, the same changes might take place in reversed order; for it is recognized by modern chemists that the reactions between two substances which produce two other substances are part of a tendency to establish a condition of equilibrium, as it is called, between the substances involved, and that this tendency can be modified by different conditions of concentration, temperature, pressure, etc., so that it is conceivable that the reaction will proceed in one direction under one set of conditions, and in the reverse direction under another.

I am indebted to Mr H. N. Stokes of the U. S. Geological Survey for the following concise statement of the present views of chemists on this subject

"It is now generally recognized by physical chemists that no reaction is complete in the sense expressed by chemical equations. Every reaction tends to a condition of equilibrium lying between the two extremes; sometimes at an appreciable distance from both; sometimes so close to one that for practical purposes the reaction may be regarded as complete. This condition of equilibrium may be varied as follows.

"(1) By an increase of the relative concentration of one of the terms of the equation which tends to shift equilibrium to the other side. This may be effected either by relative concentration of one term on the same side, or by removing the reaction products as fast as formed.

"(2) By an increase of temperature which, besides increasing the reaction-velocity, shifts the equilibrium more or less, and always toward that side of the equation which contains the most energy. The reaction velocity is the speed at which the system approaches equilibrium. In some cases this is immeasurably great, in others so small as to require ages. It is always more rapid at first, slowing down as the reaction approaches equilibrium.

"(3) By increase of pressure which shifts the equilibrium towards that side of the equation which naturally occupies less volume.

"(4) By substances foreign to the reaction which may retard or accelerate the reaction velocity, without, however, influencing the final state of equilibrium (catalytic action)."

A practical instance of the reversal of the direction of chemical reaction is furnished in Vogt's* description, already cited, of the famous silver-mines of Kongsberg, Norway. In these mines silver is in actual bulk the predominating metal. As mined, it is found mainly in the native state and very largely as wire-silver. This wire-silver, Vogt proves quite conclusively, is the result of alteration from silver-glance (argentite). He gives drawings of specimens in which the native silver is found growing out of a base of silver-glance, and in some instances still retaining small particles of glance on the ends of the wires. On the other hand, some instances are found where the wire-silver has been later changed back to silver-glance, the latter retaining the form of the wire-silver. Thus, three processes are shown in the same mine, the original deposition as glance, the change from glance to native-silver, and the reversal of this process in the change from native silver back to silver-glance.

Conclusions.—Until a much larger number of ore-deposits have been studied with a definite purpose of determining how far they have been subjected to secondary enrichment, it does not seem safe to draw any far-reaching conclusions from the observations and suggestions noted above. It has long been recognized that the superficial alteration of ore-deposits has often produced a very considerable modification of the original constitution of the deposit, and its alteration has so frequently been in the nature of an enrichment in the more valuable metals relatively to the original tenor of the ores that it has given rise to the very hasty decision that all ore-deposits necessarily become poorer in depth, which is almost as unjustifiable as the old assumption by the miner, that the nearer he got to the source of his ore in the unknown depths, the richer it would become.

* *Op cit*, p 119

The fact that ores under some conditions may be removed and re-deposited as sulphides, even below groundwater-level, opens a wide field of possibility in accounting for the unusually rich bodies of ore that are in some mines found in the middle levels, and have been fruitlessly sought for at greater depth. In many cases these have undoubtedly resulted from a concentration of material leached down from the upper portions of the deposit as they have been gradually worn down and carried away by denudation. Especially in the case of large bodies of pyritous ore carrying small proportions of more valuable metals, is a concentration of those metals by downward percolating solutions to be looked for. It is, however, not yet safe to say that all rich bonanzas in vein deposits have necessarily been formed in this way.

Although not yet supported by definite evidence, the impression is very strong with me that not infrequently the ascending currents have also produced migrations of already formed deposits and local enrichments under favoring conditions. What these conditions are, and what are the criteria by which they may be distinguished from concentrations by descending waters, it remains for future investigations to determine

Hydrographic Investigations of the U S. Geological Survey in their Relation to Mining.*

BY F H NEWELL, WASHINGTON, D C

(Washington Meeting, February, 1900)

IN 1888 the United States Geological Survey began a systematic examination of the water-resources of the West, comparable in character and scope to the study of the deposits of ores or coal. As experience was acquired, the surveys were extended to the East, until now they embrace representative localities in all parts of the United States. The object to be attained is to note and record the distribution of water-supply, and to learn, as far as practicable, the laws governing its fluctuations

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Throughout a considerable portion of the United States water is the only mineral-substance of economic importance. In the drought-stricken regions, land-values rest almost immediately upon the question of obtaining water from beneath the surface; and in other areas, the ability to mine or treat ores is governed by the excess or deficiency of the water-supply.

Mining engineers are interested in water as a mineral, or what may be termed a low-grade ore, in two ways · first, to get rid of it, where, like the country-rock, it is in the way; and, second, to make use of it, not only indirectly, through the steam-engine, but directly, as furnishing cheap power for mining, hoisting and the reduction of ores. Everything, therefore, which throws light upon the movement of water beneath and upon the surface, its quantity, and even its quality, becomes at one time or another a matter of concern to the mining engineer.

In undertaking, with limited funds, a study of the water-resources of the country, it is obvious that a plan must be sought which will yield useful returns with moderate outlay. The United States is so vast, and offers such diversity of topographic and climatic conditions, that measurement of rivers in one section gives data of little value concerning another. At the outset, therefore, it has been necessary to consider carefully the distribution of field-work so as to secure typical results, and at the same time not to diffuse it so widely as to destroy its efficiency. The one thought in mind has been to lay out the operations so that results of practical value could be attained to a reasonable degree of accuracy.

This matter of accuracy has been, and always will be, in investigations of this character, a subject for debate and controversy. At the outset it should be recognized that in the measurement of flowing water above- or underground the precision of ordinary engineering operations is not attainable, because the quantities to be measured are not fixed, but fluctuate to a notable extent, even during the process of measurement. We can ascertain the width of a river by fixing arbitrarily two points which shall represent the sides; but here an assumption comes in as to what shall be considered the sides; and usually there is a latitude for judgment of several feet. We can measure the depth, if we assume some fixed object as representing the bottom. But for the top-surface, even when arti-

ficially stilled, there is usually a pulsation ranging in time from 30 to 50 seconds or more, and giving a vertical oscillation through several hundredths of an inch; so that judgment must be exercised here. When we come to the velocity, we have the widest possible range, not only in different parts of the cross-section, but at the same point during successive moments; and here, too, judgment must be arbitrarily used. In other words, at every step of the operation of measuring a stream certain assumptions, which may affect the total by from 2 to 5 per cent, must be made.

Engineers, and especially office-men, who spend most of their lives compiling and digesting figures, are apt to lose sight of these primary assumptions, and, in their desire for accuracy of computation, to express results in decimal figures, which, if we pause to consider the primary assumptions, are not only ludicrous, but misleading. In all questions of original investigation, like that of the water-resources of the country, this element of primary assumption must be constantly borne in mind in considering the plan of work and the results attained. In the practical application of the figures of flow of water above- or underground, the tacit assumption is made that the results obtained at one time will again prevail. If, for example, the midsummer-measurements gave a stream-discharge of 100 cubic feet per second, engineers and others concerned will quote this figure and use it in their estimates, although, if they stop to think, they will admit that the stream may never again discharge a precisely equal volume, but that the low water in other years, or for an average of years, may be greater or less than this one measurement indicates. Yet, there are those who will recompute the data, and take great satisfaction in expressing the measurement as 99.63 cubic feet per second, knowing full well that there is an error of plus or minus 2 per cent in the results, and that that particular stream may next year discharge a half or twice as much at the same season.

These considerations have been taken into account, and the attempt has been made, as above stated, to obtain facts broadly representative of conditions prevailing throughout the United States, without expending money for the attainment of a degree of precision beyond the necessities of the case. There is room for wide difference of opinion as to the best way of attain-

ing this object. In the practice of the survey, localities have been selected where the results will have a local application to problems of development, and at the same time will yield data which can be applied to adjacent areas under similar topographic conditions.

The field-work can be divided into three distinct classes. First, the measurement of surface-streams; second, the survey of sites, and the estimation of capacity and cost, of reservoirs; and, third, the study of the quantity and movement of water underground. The greater part of the funds available is devoted to the measurement of surface-streams, as these have first importance, both for quantity of water and for industrial application.

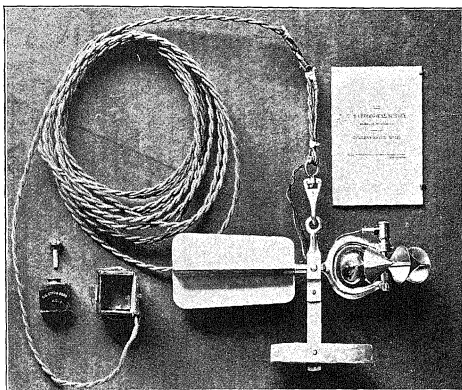
Stream-Measurement.

The practical operations of obtaining the daily flow of a stream, as developed by the experience of the Division of Hydrography, extending through twelve years, consist of two parts: first, the observing and recording of the daily height of the water; and, second, the measurement of quantity of flow for different heights of water, and computation of probable flow at all heights.

As the first step in stream-measurement, a suitable locality must be found. This, although apparently simple, is really a difficult matter. Not only must the actual conditions be favorable, the water moving in nearly straight lines over a solid bed and between well-defined banks, but the point must be accessible at moderate cost, and there must be a competent person living near, who can be engaged to serve as observer. It is usually impracticable to hire a man to stay at a given locality to observe the height of water and make measurements, and therefore places must be found where some person of reasonable intelligence can be employed at from \$3 to \$5 per month to observe and note the height of river once or twice a day, sending to the central office a postal card giving these facts. It is often possible to find a place naturally good for stream-measurement, or to come across a competent observer; but to obtain these in conjunction is comparatively rare.

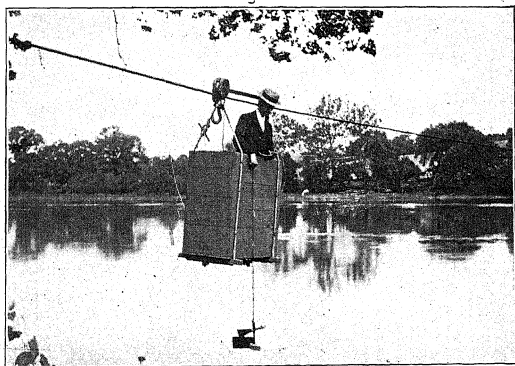
When a suitable location for permanent measurements has been found, a gauge is established so that the height of water can be easily read to tenths of a foot. This may be either

FIG. 1.



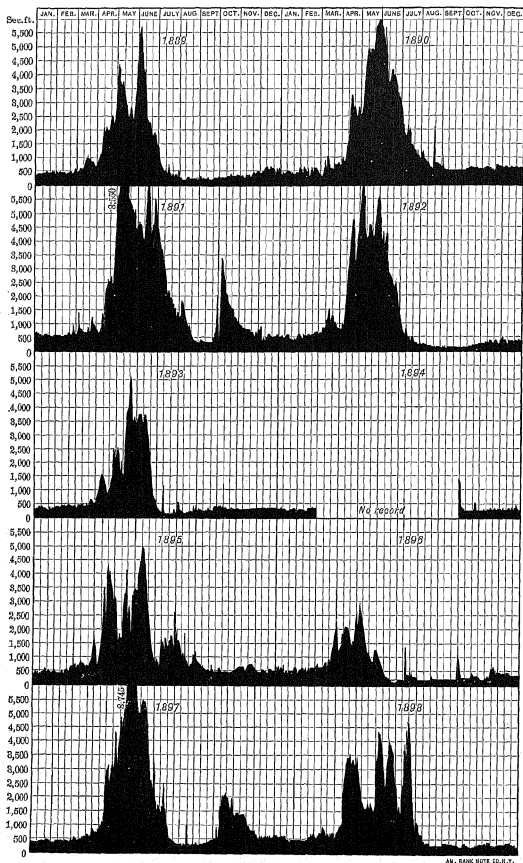
Small Electric Current-Meter and Battery. (The Battery has Been Removed from its Leather Case and the Zinc Drawn Out. The Small Buzzer is not Shown, Since it is on the Back of the Leather Case.)

FIG. 2.



Method of Using Electric Current-Meter from Suspended Car.

FIG. 8.



Graphic Representation of the Flow, in Cubic Feet per Second, of the Rio Grande at Embudo, N. M., from Jan. 1, 1889, to Dec. 31, 1898.

a vertical or inclined scale, fastened to a pier or attached to supports firmly bedded in the bank. If inclined, the gauge is graduated, after setting, to vertical tenths of a foot, thus affording a magnified reading, which is always at the shoreline. Sometimes a wire gauge is used, a weight being lowered from a bridge or overhanging support, and the distance noted along the horizontally-placed scale. Whatever the device may be, great care must be taken that it be referred to permanent bench-marks, and maintained without alteration.

From time to time the engineers, or hydrographers, as they are termed, visit and inspect the river-stations, and make measurements of the volume of flow by means of current-meters. Of these, many forms are in use, preferably those having electrical sounders, so arranged that every revolution of the wheel causes a click or buzz in a small sounder in the hand or pocket of the hydrographer. Many automatic devices have been tried, but in the long run this type, an example of which is shown in Fig. 1, has proved most satisfactory. In using it, the hydrographer counts and records in a notebook the number of repetitions of the sound during 50 seconds. The meter is placed in various parts of the cross-section, by suspending it from a boat or bridge, or, more commonly, from a car, in which the hydrographer sits. This is supported by a stout steel cable extending across the stream, as shown in Fig. 2.

From the occasional measurements of discharge there is constructed, usually by graphic means, a table showing the volume of flow for each tenth of a foot in height of the water. From this table the discharge is placed opposite the corresponding height for each day, thus giving the fluctuations of the stream, which may be stated in terms of the maximum, minimum and mean per month, or given graphically in diagrams. Such a diagram is given, as a specimen, in Fig. 3, which shows the fluctuations of the Rio Grande at Embudo, New Mexico, from 1889 to 1898, inclusive. If the area drained be known, these results can be expressed in units of area and volume, or in depth over the entire catchment-basin.

Reservoir-Surveys.

The volume and fluctuation of a stream being known, it is at once apparent that its application to industrial uses can be

greatly widened by controlling the flow. This is especially the case in those regions, outside of the glaciated area of the north-east, where such natural regulators as marshes and lakes do not exist. The U. S. Geological Survey, in preparing the great topographic map of the country, discovers many localities where water might be held by building dams, and the question then arises whether such constructions would be justified by the capacity of the regulating reservoirs thus created, as compared with their cost. There are often many alternative schemes to be considered in reaching a conclusion. For this purpose, systematic surveys of reservoir-sites have been undertaken, the basin being mapped with contour-intervals of from 5 to 10 feet, sufficient to give the capacity within, say, 2 per cent. Of the locality where a dam might be built a larger map is made with greater detail, usually showing contours at 1-ft. intervals.

The question of foundations is usually the most important, and diamond-drills or other apparatus are used to determine the character of the bed-rock. There is considerable latitude in the character of these reservoir-surveys: in most instances a simple reconnaissance and sketch are sufficient to develop obstacles such as to render further survey unnecessary. When it is found that the conditions are favorable, a more careful examination is made. As a matter of course, if the work is finally built, the constructing engineers will probably modify some of the features in detail; but the object kept in mind by the Geological Survey is to ascertain the larger facts, such as will serve for guidance to engineers or investors in considering various projects.

The reservoir-sites surveyed or segregated have been listed or described in various annual reports of the Survey, beginning with the Eleventh. Reference may be made to these volumes for details. During the year 1899, surveys in great detail have been made of three sites on the Gila river, in Arizona; of one, for a large reservoir, in the Hetch-Hetchy valley, on the head-waters of Tuolumne river, California, and of several on the Rio Grande, in New Mexico. The results of these surveys will be given in the Twenty-first Annual Report, if not in earlier publications.

It is proposed to continue these surveys as rapidly as funds may be available, giving precedence to those in which such

data have greatest public importance and interest. As a result of several years' experience, this office has a corps of engineers provided with instruments and equipment, and is doing the work, probably, with greater speed and economy than private or corporate enterprise could ordinarily achieve in a single undertaking of this class. The question of expense has been carefully considered, and the methods in use have been adapted to secure the maximum efficiency at a minimum cost, with due regard, of course, to the importance and the permanent character of the results.

The question is frequently asked, whether the United States will build such reservoirs. That is a subject on which the members of the Geological Survey cannot express an opinion. The duty of the Survey is to ascertain the existence of reservoir-sites and the cost of storage-works, whether these are ultimately built by individuals, by corporations, or by the State or Federal government. Some of the reservoirs surveyed or examined have already been constructed, others may be; but the most important are of such magnitude that they cannot be built except by the use of public credit in one form or another. It is to develop these facts that examinations are being made, so that intelligent action can be taken by the people.

In pushing forward these reservoir-surveys, co-operation is sought wherever practicable, as in the case of the topographic mapping. With several States there is an arrangement by which topographic work within the State is pushed forward more rapidly than would be possible otherwise, the State making an annual appropriation in aid of field-expenses, an equal or greater amount being spent in field-work by the Geological Survey, and the resulting map being prepared and published by the latter, with proper credit to the State authorities. Such an arrangement was under consideration for the case of reservoir-surveys in California during the recent session of the Legislature of that State. Should co-operation in reservoir-surveys be offered by States, and appropriations therefor made, it is anticipated that equal sums will be expended by the Geological Survey to hasten the completion of the work within those States.

The relation of the Geological Survey to reservoir-surveys may be summed up as follows:

The Survey was created primarily for the purpose of examining and classifying the public domain, including the mineral resources and the waters. It is specifically authorized to survey reservoir-sites, and to ascertain the extent to which the arid region can be redeemed by irrigation. It is making general explorations for the reservoir-sites, and surveying a few of these in detail each year. It will extend its operations as fast as funds will permit, the work being more rapidly advanced where State co-operation can be had. Its officers have no concern with the question whether these reservoirs are to be built by private capital or by public funds, their work being to ascertain the facts, such as capacity and cost of reservoirs.

Ground-Waters

While the greater part of the available waters of the country occur on the surface, those which are found beneath the surface often have more immediate importance to mining engineers, since these may retard their operations, or, on the other hand, may be the object of search. In order to study these, it is necessary to know as much as can be ascertained concerning the rocks in which they occur, since the quantity and movement of the waters underground are governed by the porosity and permeability of the rock-layers. It is therefore necessary to begin with a study of the nature, position, stratigraphical or structural inclination, and physical condition of the water-bearing rocks, so far as these factors govern the movement of the water. This must be done by examining the surface-outcrops and well-records, and by experimental treatment of samples of the various pervious and impervious materials encountered.

Under the Great Plains of the United States, where perennial waters are not to be found, there are layers of sandstone, some of which are relatively pervious to water, and which, receiving it at their outcrops on the Rocky Mountain flanks, transmit it for hundreds of miles. The drill—penetrating these sandstones—allows the water to rise and overflow the surface, furnishing an abundance for domestic and municipal use, as well as for various industries and for agriculture. Some of these sandstones may contain as high as 38 per cent. of their volume of water. Broad sheets, like the Potsdam, St. Peter's, and Dakota formations, are in effect storage-reservoirs of vast ca-

capacity, containing for every 100 ft. in thickness from 15 to 30 ft. in depth of water. In order to make this supply available, it is necessary to know, not only the extent of these and similar sandstones, but also their condition as regards permeability, since their texture varies in different localities. A series of maps is being prepared, showing the depth beneath the surface of these water-bearing sandstones, and indicating by conventional colors whether the waters will probably rise to the surface and form artesian wells. By these maps, the uncertainty of deep-well drilling will be to a considerable extent removed, and mining engineers will be able to proceed in their search for underground waters with a reasonable degree of reliance upon the practicability of obtaining the needed supply.

A Peculiar Clastic Dike near Ouray, Colorado, and its Associated Deposit of Silver Ore.*

BY F. L. RANSOME, WASHINGTON, D. C.

(Washington Meeting, February, 1900)

The dike here described is exposed in the workings of the Wedge and Bachelor mines, on the southern side of Red Cañon, north of the town of Ouray, Colorado. Its course is north 80° east, or nearly east and west, and it hades to the north about 10° . It rarely outcrops, and was nowhere seen at the surface near the mines. A specimen collected by Dr. A. C. Spencer about two miles to the westward, near the mouth of Red Creek, indicates, however, a probable exposure of the dike near this point.

The Wedge and Bachelor mines lie in a nearly horizontal series of fine-grained, light-grey sandstones, alternating with beds of very fine-grained shale of the same color. The shale as encountered underground is unusually compact and massive, but weathers readily on exposure, and splits much after the manner of ordinary shale. When fresh it closely resembles some finely arenaceous limestones, but it does not effervesce with acids, and is essentially a fine, indurated, siliceous silt. Near the surface, and near the top of the sedimentary series as

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exposed in the vicinity, is a bed of black shale, which I was informed by the foreman of the Wedge has a local thickness in the shaft of about 100 feet, with beds of sandstone about 25 feet thick above and below. The exact geological age of the sediments in which the mines are working has not yet been determined. They are stratigraphically above the Dolores formation (Triassic) and below the San Miguel conglomerate (Eocene). Their general dip is southeasterly at an angle of about 10° .

The dike occupies a fault-fissure which cuts the nearly horizontal sandstones and shales. The dislocation was effected by normal faulting with a throw of apparently only a few feet. The width of the dike varies up to three feet, and is fairly regular. It sometimes splits, sending out long wedge-like tongues into the country-rock, or, coming together again, encloses a "horse" of shale or sandstone.

The material of the dike, commonly spoken of as "porphyry" by the miners, is a clastic rock of striking appearance. It consists of very abundant fragments of black shale and a smaller number of light-colored fragments and pebbles, all cemented together by a light grey matrix. The particles of shale are usually flat, and in the majority of cases lie with their greater dimensions parallel to the walls of the dike (Fig. 1). This is particularly true near the contact, where the pieces of shale exhibit deformation and other evidence of pressure. The flakes of shale vary much in size, the largest in the hand-specimens collected being 6 cm. in greatest diameter and 4 mm. thick. The light-colored fragments embedded with the shale in the grey matrix comprise more or less rounded pebbles, consisting of a fine saccharoidal aggregate of quartz. The matrix in which these fragments lie appears to be made up of the same materials as the latter, only much more finely comminuted—to have been, in fact, a fine mud composed of broken-up shale, both black and light grey, and sandstone. Examined under the microscope, this gray matrix is seen to consist of minute flakes of shale often showing deformation by pressure, and numerous angular grains of quartz of various sizes down to two- or three-hundredths of a millimeter in diameter. A few of the large quartz grains are aggregates and appear to be particles of vein quartz. There is some sericite present, and an indistinct

cloudy material which seems to partly fill the rôle of cement. This is not a carbonate, as might have been expected, but is possibly barite.

The contact of the dike with the walls is perfectly sharp, and it is not difficult to secure both rocks in a single hand

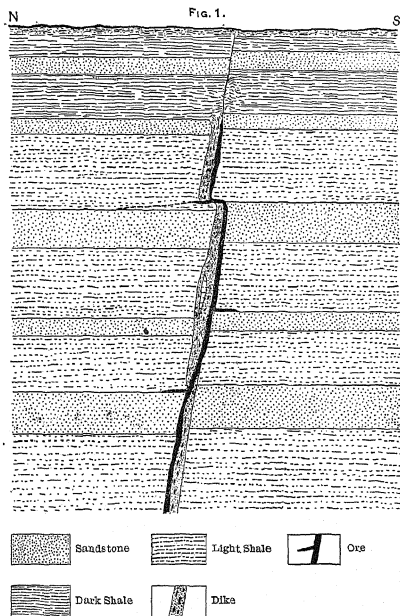


Diagram showing General Relations of the Red Cañon Clastic Dike, Ore-Deposit, and Enclosing Sandstones and Shales. Transverse North and South Section across the Dike and Vein. Width of dike greatly exaggerated to show structure.

specimen. Frequently, however, there is a thin clay seam or gouge between dike and walls, sufficient to cause easy separation in mining.

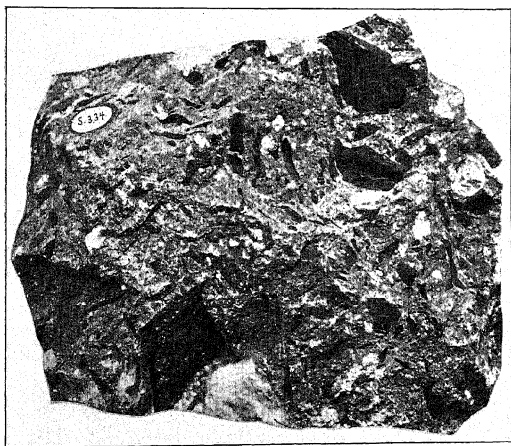
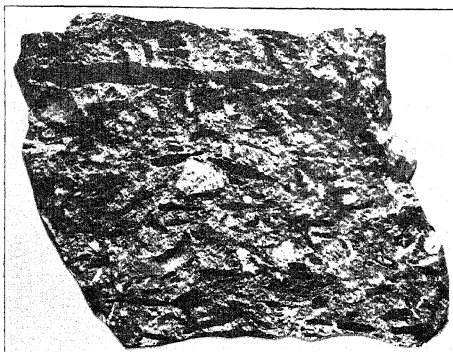
In its relation to the enclosing sandstones and shales the dike simulates perfectly the behavior of an igneous dike in-

truded under pressure, although there is, of course, no thermal contact metamorphism of the walls. In whatever manner the filling material was first conducted into the fissure, it is evident, both from the phenomena of intrusion and from the internal structure of the dike-rock itself, that it was subsequently subjected to very considerable pressure. This pressure was sufficient to force the material into all the open crevices, and to cause such flowage in the filling mass that the thin flakes of black shale were rotated into an approximately parallel orientation with the walls, and were in some cases bent, fractured or drawn out into lenses.

As previously noted, the dike is not exposed on the surface, and the first discovery of it, and of the associated ore-body, was in a tunnel run on the Bachelor claim, apparently with the general object of prospecting the hill-side. The Wedge mine joins the Bachelor on the west, and is worked through a shaft which was sunk to strike the continuation of the vein found in the Bachelor. The present depth of this shaft is about 630 feet. About 100 feet below the surface a short drift has been run in the bed of fissile black shale previously referred to. These shales are cut by the fault-fissure and locally crumpled and broken; but the fissure is pinched, and neither dike nor ore occurs in the black shales as far as prospected. From the bottom of the black shale, however, down to the lowest level attained in the mines, 730 feet, the dike is a constant and characteristic accompaniment of the ore, and is the unfailing guide followed by the miners. The Bachelor mine is worked through a tunnel which cuts the dike near the 600-foot level of the Wedge. A shaft has been sunk in the Bachelor 100 feet below the tunnel level, but without revealing any change in the character and regularity of the dike.

The origin of the dike appears to be deducible from the facts presented. A fissure was formed, accompanied by some faulting, and was filled, chiefly from above, by fragments of the soft fissile black shale, which does not occur in the stratigraphically lower beds exposed in the immediate vicinity, and partly by material from the lower light-colored beds forming the present walls. The fragments from both sources were well mixed together, and probably formed a stiff mud crowded with fragments of shale. Subsequent to the filling there must have

FIG. 2.



Specimens from Clastic Dike. Upper Illustration shows Parallel Arrangement of Shale Flakes as seen in Transverse Sections. Lower Illustration shows Fracture-Face Approximately Parallel with Walls of Dike. Both natural size.

been sufficient movement and pressure to bring a majority of the shale flakes lying near the walls into parallelism with the latter. The hypothesis that the shale fragments, instead of falling into a partly open fissure, were dragged down by the movement of faulting, has not been overlooked. It is probable that some such action took place, but it cannot alone account for the great abundance of fragments of black shale more than 600 feet below the lowest horizon at which these shales occur, unless there is postulated a fault of at least 600 feet throw. It is not impossible that there actually was a fault of this extent, followed by a reversal of the movement, but for this there is no direct evidence. Moreover, black shales may occur in the carboniferous strata which are probably present beneath the red-beds of the Trias. But it seems very unlikely that fragments of black shale identical with that of the upper bed should have come up from such great depth through the whole thickness of the red-beds.

Fissures filled with indurated sand—the so-called “sandstone dikes”—are by no means rare, and have been described by many observers in various parts of the world. In many cases, such as the sandstone dikes found cutting granites by Cross* in Colorado and by Ussing† in Denmark, the filling material evidently came from above, and was forced downward into the fissures. In the case of the sandstone dikes cutting Neocomian clays in Russia, as described by Pavlow,‡ it is demonstrated, through the evidence of fossils, that the sand-filling came from above. Strickland,§ Darwin|| and R. D. Irving¶ have all described similar sandstone dikes, which they regarded as fissures filled from above. Diller** has given a very thorough description of sandstone dikes cutting Cretaceous sandstones and shales in California. His conclusion was that they were injected from below, in the form of quicksand, into fissures in the overlying beds probably produced by earthquake shocks.

The various sandstone dikes above referred to are all com-

* *Bull. Geol. Soc. Am.*, vol. v, pp. 225-230. 1893.

† “*Geological Survey of Denmark*,” Part II, No. 10. 1899.

‡ *Geolog. Mag.*, N. S., Decade IV., vol. iii, pp. 49-53. 1896.

§ *Trans. Geol. Soc.*, London, Ser. II., vol. v, p. 599. 1840.

|| “*Geolog. Observations on Coral Reefs*,” etc. 1851. Pl. III., p. 150.

¶ *U. S. Geol. Sur., Monog.* v, pp. 140, 292-293.

** *Bull. Geol. Soc. Am.*, vol. i, pp. 411-442. 1890.

posed of more or less well-rounded sand grains, with but few angular particles. The present dike, while of the same general class, cannot be called a *sandstone* dike, as it is composed of angular fragments of shale and quartz of widely varying sizes. It seems best to refer to such intrusions as *clastic dikes*, being careful to avoid using this term for possible igneous dikes, which have been brecciated by movement prior or subsequent to final solidification.

Clastic dikes, apparently showing close similarity to the one forming the subject of the present note, have been described by Béla von Inkey¹ in the celebrated mining district of Nagyág, in Austria. These *Glauchgange*, or more briefly *Glauch* (a word meaning barren or unprofitable), as they are called by the Austrian miners, are abundant in the vicinity of the ore-bodies. They show great diversity of strike and hade, and their intersections prove that they belong to at least three different periods of formation. They vary from the thinnest sheets up to 60 feet in width, and are composed of angular fragments of the adjacent country-rock, embedded in a fine, sandstone-like matrix. The size of these fragments is roughly proportional to the size of the dike in which they occur. They may be 2 or 3 feet in diameter. The dikes are older than the ore-bearing veins, and are often cut by the latter. The veins sometimes run alongside of and parallel with the *Glauchgange*. The origin of these curious dikes has been discussed by von Groddeck, Pösepný and others. Von Inkey advances the convenient but scarcely well-supported opinion that they are actual intrusions from mud volcanoes. In the general character of their filling the *Glauchgange* show some resemblance to the Colorado dike. Their origins, however, may be somewhat different, and have certainly not been proved identical. According to von Inkey, similar dikes occur in other mining districts in Austria, notably at Voróspatak, where they are locally termed *Glamm*. The *dowkies* of Wales may also be analogous phenomena. It is evident that it may, at times, be difficult or impossible to draw a sharp distinction between a fissure filled in the manner described for the Red Canon dike and an indurated fault-breccia. In fact, all gradations are conceivable between the processes involved and between the results attained.

* "Nagyág und Seine Erzlagerstätten." Budapest 1885. pp 146 *et seq*

It is interesting to note, in this connection, that the ability to take the form of an intrusive mass is limited neither to igneous rocks nor to clastic dikes of the kind described, but may be assumed under certain favorable circumstances by various asphaltic compounds, as in Southern California,^{*} Utah[†] and elsewhere.

As far as is known, the strictly sandstone dikes hitherto described by various observers have not possessed any economic importance. The Red Cañon dike, however, has an added interest and significance in that it has determined the locus of a workable ore-deposit, and is a valuable guide to the miners in the exploitation of their ore-body. It thus resembles still further the occurrences of Nagyág.

The ore associated with the dike is essentially a high-grade silver-ore, in which the important mineral is argentiferous tetrahedrite, or freibergite, accompanied by galena and a little chalcopyrite and sphalerite. The gangue of the richest ore is chiefly barite, although some quartz occurs. The deposition of the ore, although genetically connected with the dike, was subsequent to the formation of the latter. It occurs sometimes on one side, sometimes on the other side, and occasionally within the body of the dike. Its more common position is between the dike and the adjacent country-rock, and it is usually, although not always, adherent or "frozen" to its walls. It occurs sometimes in a vein 6 to 8 inches wide, and sometimes in a breccia zone wherein the ore surrounds angular fragments of dike and country-rock.

In the course of working the ore-body, the miners have developed the fact that the dike is faulted in more than one place by bedding-faults which, as far as observed, have resulted in a movement of the upper portion of the dike northward relatively to the lower portion.

Thus in stopping upward the dike is sometimes found to end abruptly. The ore, however, is not cut off, but turns suddenly into a flat seam or "roll," which may be followed from 10 to 20 feet before it again resumes its nearly vertical attitude and the dike reappears. The general relation of dike, country-rock and ore is indicated in the accompanying diagrammatic figure (Fig. 1.) This is not an accurate section of any single

^{*} E. W. Hilgard, *10th Ann. Rept. Cal. State Mining Bureau*, pp. 763-772. 1890.

[†] G. H. Eldridge, *17th Ann. Rept. U. S. Geol. Sur.* Part I, p. 938. 1897.

portion of the Wedge or Bachelor vein, but merely a generalized explanatory sketch.

The ore is not strictly confined to the dike itself, but frequently runs off for some distance as thin, nearly horizontal sheets, lying between the beds of sandstone and shale. There is in these cases no trace of replacement of the material of the beds. The ore has evidently been deposited in narrow openings formed by movement of the beds upon each other. Such ore-sheets are seldom more than 6 cm ($2\frac{3}{8}$ inches) thick, but are generally high grade.

In general, the deposition of the ore is definitely confined to the planes of fissuring and movement. There is scarcely any evidence of mineralization or local alteration of the wall-rock, such as is rarely absent wherever productive veins traverse igneous rocks. Minute specks of ore can occasionally be detected in the body of the apparently unfractured portion of the dike, but they are insignificant, and the dike-rock presents a remarkably fresh and unaltered appearance when its close relationship with the ore is considered.

From the position of the ore and from the fact that it often includes small fragments of the dike-rock, it is seen to be younger than the dike. The dike had been formed and somewhat indurated when the rocks again yielded to stress in such a way as to produce movement of small extent, and openings of moderate dimensions, chiefly along nearly horizontal strike faults and along the line of the dike. These openings were filled with ore deposited by solutions which, it is supposed, from analogy with other deposits, came up from sources mainly situated at some unknown depth below.

In a deposit of this unusual character, closely associated with a dike filled from above, the question of the permanency of the ore-body down to the practical limit of mining becomes a particularly important one. The fact that the fissure is also a moderate fault, and the great regularity of the dike for the vertical distance of 700 feet, already explored, both argue for the continuance of the deposit to a considerably greater depth than that now reached in the mines. But the possibilities for interruptions and irregularities in such an ore-deposit as it is followed downward are so numerous as to make any prediction unsafe. It is likely that at three or four hundred feet below

the present workings the coarser sands and conglomerates of the red beds may be encountered, an entirely different set of conditions may there obtain, and the ore change its character or be lacking entirely. Questions of this kind are usually sufficiently difficult to answer, even when the geology of the region has been thoroughly investigated. In the present case the necessary data are lacking

Some Notes on the Nome Gold Region of Alaska.*

BY F. C. SCHRADER AND ALFRED H. BROOKS, WASHINGTON, D. C.

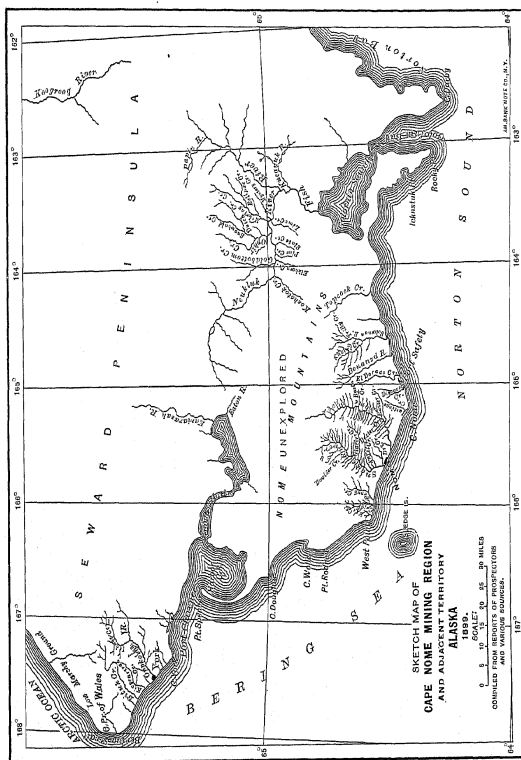
(Washington Meeting, February, 1900)

LAST fall (1899) we had the good fortune to be able to spend a few weeks in the new placer gold-mining region of Alaska, which is known as the Nome region. Cape Nome, after which the region has been named, and which forms the southeastern corner of the Nome Mining District, is an unimportant promontory on the southern coast of the Seward Peninsula (see map, Fig. 1). The name Seward has recently been given to the great peninsula which forms the northwestern extremity of Alaska. To the north of it is the Arctic ocean, to the south Bering sea, while its westernmost extremity, Cape Prince of Wales, is separated from the Asiatic coast by the Bering straits.

The coast line of the peninsula is of a cusped character, consisting of a succession of sandy, crescent-shaped beaches and rocky headlands. The interior has been but little explored; but we know that it is comparatively rugged, the higher mountain peaks rising probably from 4000 to 5000 feet in elevation. The mountains have an easterly and westerly trend, and the water-shed between the two oceans probably nearly bisects the peninsula. At Golofnin bay, the southeastern part of the Seward peninsula, some spruce is found, but to the west the region is entirely timberless, except for a sparse growth of stunted

* Published by permission of the Director of the U. S. Geol. Survey. A more detailed account of this region is now in print, entitled "Preliminary Report on the Cape Nome Gold-Region, Alaska," by Frank C. Schrader and Alfred H. Brooks. Senate Document No. 236, 56th Congress.

alder and willow, found near the streams. The Nome region proper includes an ill-defined area in about the center of the



southern margin of the Seward peninsula, 100 miles southeast of Bering straits. (Compare map, Fig. 1.)

Here a crescent-shaped, moss-covered plain stretches inland from the coast, having an extreme width of 4 to 5 miles.

Cape Nome forms its eastern, and West Point its western apex. To the north this plain is broken by a succession of terraces, the highest one of which merges with the rounded slopes of the mountains. The drainage of the region is taken to the Bering sea by several streams of considerable size, which have broad valleys with gently rising slopes. In their lower courses these rivers meander sluggishly through the tundra plain. The streams tributary to the rivers have narrow valleys, while the gulches are usually sharply cut. The mountains, rising to 1000 to 1500 feet, have rounded moss-covered slopes, broken here and there by rock cliffs. A striking feature of the topography is a series of benches and terraces which occur in the plain and on the mountain slopes. The lowest of these is the coastal plain, which is about 30 feet above tide water. About 2 miles inland is another bench, about 100 feet in elevation, and we observed them at varying intervals up to about 1200 feet.

Our short visit to the Nome region did not permit of working out any details of the bed-rock geology. The commonest rocks are thinly-bedded blue limestones and quartz mica schists, which are found interbedded, and are both undoubtedly of clastic origin. These rocks are often locally much metamorphosed, the blue limestone being changed to a marble and the schist to a thinly laminated mica schist. Besides the limestones and schists we also found a belt of gneisses and mica schists, whose origin is doubtful.

The series is closely folded, often much sheared, and has varying dips. The usual strike is about northeast and southwest. There is a marked absence of intrusive rocks in the region studied by us. In only one instance did we find a dike, and this was of an aplitic character and but a few inches wide. The beach-gravels at Nome often contain pebbles of granite and other igneous rocks, but we did not find these rocks in place. Prospectors report a large area of granite some 10 or 12 miles inland.

In the Nome region the rocks are much jointed and fissured. Quartz and calcite veins, often containing sulphides, are common. In some localities the mineralizing solutions have penetrated throughout the rocks.

From the standpoint of the gold-seeker the most interesting

formations of the region are the gravels. These are found forming stream terraces along the creeks and marine terraces in the tundra, and on the mountain slopes. Their presence indicates a gradual elevation of the entire area. The pebbles of the gravels, as far as we have observed, can usually be traced to some local source.

Gold

The gold of the Nome region has, so far, all been obtained from placer-deposits which can be conveniently grouped as gulch-placers, bar-placers, beach-placers, tundra-placers, and bench-placers. During the past season only those of the gulch and beach have been important gold-producers. No facilities were available for exploiting the tundra-deposits, and the benches have not, as yet, been investigated.

The amount of gold produced during the past season cannot be definitely estimated. While there are, as a rule, fairly reliable data, as to the production of the gulches and creeks, the amount taken from the beach can only be roughly approximated. From the best information we could gather, we believe that the production of gold of the entire belt during the season of 1899 approaches \$3,000,000.

The coarse gold, as far as present developments show, is largely confined to the creek- and gulch-diggings, ranging from the size of a pin-head to nuggets weighing several ounces. Two have been found on Anvil creek weighing 20 to 25 ounces. Much of this gulch-gold is about the size of No. 3 shot, while nuggets from one-half to one ounce are not uncommon. It is probable that much of the fine gold is lost by the more or less primitive method of extraction now in use.

The gold is usually rounded, and often smoothly polished. In color it is rather dull, and somewhat resembles tarnished brass. The nuggets are round and sub-angular, but seldom flat. Small vitreous quartz masses are not unfrequently found attached to the nuggets.

Gulch-Placers—The creek gold usually occurs on, or very near, bed-rock under a thickness of 5 to 8 feet of gravel. In the diggings, the pay-streak is of varying thickness, but the gravel usually carries some gold, or at least "good colors," from the surface down. The flood-plain or gravel deposits of the stream in or beneath which the gold occurs, measured from

rim-rock to rim-rock, varies from 20 to several hundred feet in width on different creeks. A cross-section of the gravel at any given point would show the gold not evenly distributed, but more or less gathered into zones. This pay-streak trends parallel with the creek valley. It is not necessarily continuous, but often occurs in detached pockets which are sometimes very rich.

The gravels occurring with these placers vary from medium size to fine, and are usually poorly assorted, with indistinct stratification. In the area examined by us on Anvil and Glacier creeks, the pebbles were chiefly limestone and mica schist with much calcite and quartz of vein origin. All of these were frequently found to be highly mineralized. In washing the gravels of the gulches and the creeks, much *ruby sand* and *black sand* is obtained. The former is chiefly garnet and the latter magnetite. These minerals having a high specific gravity are concentrated with the gold in the pay-streaks.

Bar-Placers.—In the lower reaches of the Snake river, and of the other large streams, gold is reported to occur on the bars, also in apparently workable quantity. It is here much finer than in the creeks and gulches, but not so reduced as that in the beach. So far as we learned it is variously mingled with the gravels and the sand constituting the bars, and, like them, was deposited by the rivers and streams which brought the material down from the creeks and gulches. It was on the bars of Snake river that the Nome gold was first discovered.

Beach-Placers.—Normally in the beach-deposits there is fine gold, gold-sand, and some flake-gold. The particles are much rolled and flattened, and range in size from that of a small pin-head to dust- or *flour-gold*. With only the crude appliances for separation at hand during the past season little of the *flour-gold* has as yet been saved. Small nuggets amounting to about \$1 50 in value have been found but are relatively rare.

The beach-gold, when separated, is bright in color, having much the appearance of fresh brass or gold filings, and is usually of uniform grain. It is of irregular shape, usually flattened with rounded surfaces, and bears evidence of the grinding action of the surf which reduced it to its present fine state.

This beach-gold occurs in the beach-placers, a strip of com-

paratively fine gravels and sand, 100 to 150 yards wide, extending parallel to the shore between the frontal edge of the tundra and the water-line. In the Nome region it has been found in the beach from a point a mile east of the town westward for some 10 or 12 miles. Beach-deposits were also reported from other localities along the southern margin of the Seward Peninsula.

The richest pay-streak of the beach-deposits usually lies on what is locally called "bed-rock." This is a tenacious clay of varying consistency. It is normally blue in color, but is often stained yellow by iron, and frequently contains some carbonaceous matter and some sandy matter. The clay varies in depth from a few inches at the edge of the tundra to 6 or 8 feet near the water line. It seems to be a bed which dips gently toward the sea. It should be noted, however, that it was not definitely determined that this bed-rock is in all cases the same stratum of clay, for such clay-beds are likely to occur anywhere in the gravels.

The strata above the clay-beds consist of well stratified *ruby sand*, *black sand*, fine gravels and sands, with occasional layers of shingle. The pebbles are of the rock types which have been described, as well as of calcite and quartz. As in the case of the pebbles of the gulch gravels, these frequently show some mineralization.

The gold lying on the clay "bed-rock" is not evenly distributed, but occurs in more or less concentrated patches. The thickness of the pay-streak is a variant of the methods used in extracting the gold. With the crude methods employed by many of the miners only the richest portion of the pay-streaks are worth working. This includes, in some instances, only the scrapings of the upper surface of the clay-bed, in others, several inches of the overlapping gravels. The pay-streaks vary in width from a foot to several yards, can often be traced in more or less disconnected patches from near the tundra to low tide, and their longer axes seem to lie at right angles to the shore-line. This trend is probably ascribable to the concentrating action of the waves and possibly to the tide when the gold was deposited. The gold has been found from the grass roots of the tundra to low tide. There is a strong probability that this deposit extends seaward, but as yet we have no decisive evidence on this point.

The richness of the beach-placers is very variable. Nearly all the beach-sand carries some colors, and we have seen as much as one dollar to the pan obtained from the pay-streaks in several localities. As above described, the richest pay-streaks of the beach lie on or close to the clay-beds. Another mode of occurrence is in the thin layers of *ruby sand* and *black sand* which occur interstratified along with the beach-gravels. The position of such layers, which rarely exceed two in number in any given section, is usually toward the base of the section. The pay-dirt from the *ruby sand* layers consists chiefly of fine garnets and magnetites, with a few vitreous and rose-quartz grains.

Tundra-Placers.—As has already been stated, the coastal plain or tundra is underlain by gravels similar in character to those of the gulches and the beach. There is every reason to believe that these gravels are gold-bearing, though they have as yet received but little attention from the prospectors. As we have already noted, "pay-dirt" has been found a few inches below the surface at the edge of the tundra near Nome. This is the only fact in regard to gold in the tundra which we could verify by personal observation.

The following section, Fig 2, of the tundra-gravels is compiled principally from information furnished by prospectors and miners, and must be considered as of approximate accuracy only. Underneath the dense and spongy growth of moss and grass is a layer of dark brown or black peat, varying from 2 to 20 inches in thickness. This peat is usually of a coarse fibrous character, and is formed principally from moss and grass by vegetable decay. Below the peat a layer of blue tenacious clay about a foot in thickness is usually found. This rests upon stratified sands and gravels, and includes considerable white sand, similar to that of the beach. There are also a few thin layers of *ruby sand* and *black sand*, occurring at irregular intervals, that often carry gold in commercial quantities. These are usually found resting upon a blue or yellowish clay of a tough impervious character, which is often termed bed-rock by the miners.

The hard or true bed-rock is reported to be a soft sandstone or mica-schist. These lithologic terms are used rather loosely by the average miner, and we believe that the same bed-rock series exposed in the gulches underlies the gravels of the tun-

dra. Where this bed-rock has been reached, it is usually at a depth of from 20 to 40 feet. It must not be inferred that this is a measure of the average thickness of the tundra gravels, as the test-pits from which data were obtained were too few in number. It is not impossible that the tundra-gravels may, in many localities, exceed 100 feet in thickness. While no systematic prospecting of the tundra-gravels has yet been undertaken, some test-pits have been sunk which have shown very favorable indications of gold. The localities of these test pits are all within a few miles of Nome, and they have yielded from 1½ cents to 35 cents to the pan.

Bench-Placers.—The bench-placers of the region have, as far as we know, received little or no attention from the prospectors. Some of the low benches near the creeks have been shown to yield gold, but the higher benches and terraces have been disregarded, chiefly, it seems, because of the difficulties in obtaining water. As has been explained, these benches and terraces have a similar origin to that of the tundra-plain, and as their material has a similar source, they are likely to contain gold. Whether this gold is sufficiently concentrated to prove of commercial value is a question for the prospectors to settle. A good number of bench-claims have been staked, and it is to be hoped that the assessment-work of this year will throw more light on this subject.

Veins.—In a new region, like that of Nome, the prospector naturally turns first to the deposits which will yield immediate profit, and therefore vein- or quartz-mining receives but little attention. In the arctic region, moreover, prospecting for mineral veins is much impeded by the thick coating of moss which covers most of the surface of the country. We have, therefore, but little definite information in regard to mineral veins of the region.

In the discussion of the geology, we noted that the limestones and mica schists contain many quartz and calcite veins which are frequently mineralized. We observed both copper and iron pyrites in these veins, and we have it on good authority that gold-bearing quartz veins have been found in the region. The placer-gold, as we have noted frequently, has small grains of quartz attached to it. In the beach-gravels, rounded fragments of ore are occasionally found, consisting chiefly of copper and

iron pyrites. One of these (assayed for this office by E. E. Burlingame of Denver, Colorado) yielded 0.12 ounce of gold, with a trace of silver, to the ton

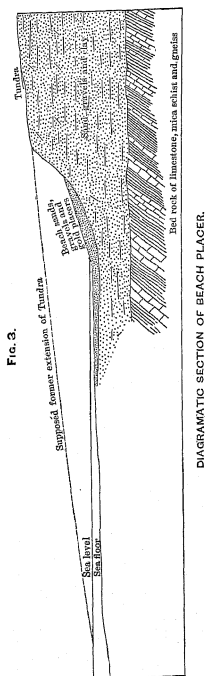
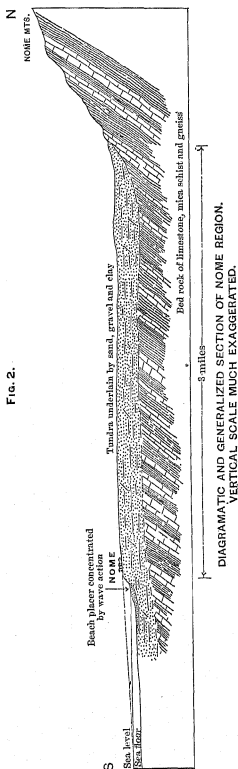
As far as it goes, the evidence points to a derivation of the gold from the mineralized veins and country-rock above described. We wish to emphasize this, because of the popular idea that the Nome placer-gold has been brought from great distances by the action of ice, or through some convenient convulsion of nature

Origin of Beach-Placers—The beach-placers are of such interest and importance to the Nome region that we deem it best to add some more detailed account of their origin. An examination of the accompanying sections (Figs. 2 and 3) will show that the beach-deposits are largely a concentration of the gold carried by the gravels and sands of the tundra. The waves are constantly cutting away the base of the bluff that nearly everywhere forms the tundra on the seaward side (Figs. 2 and 3). As the material is thus eaten away the gravels and sands are carried seaward by the undertow, while the gold, because of the greater weight, is left on the beach. It will work its way downward more or less in the loose sands near the water-line, and may subsequently become buried. This action undoubtedly took place at former stages of elevation of the coastal plain; and we would expect to find lines of old beaches in the tundra. This should be borne in mind in considering the possible commercial value of gold-deposits in the tundra gravels. Only along these old shore-lines or in the bars of abandoned stream channels should we expect to find it as concentrated as it is on the present beach.

The amount of gold in any given stretch of the beach may be used as a rough criterion of the gold-contents of the tundra. An examination of Fig. 3 illustrates this point. The gold in the beach-placer should be roughly equivalent to the amount of gold disseminated in that part of the tundra which has, by the cutting action of the waves, furnished the gravels for this beach placer.

Other Gold-Districts of Seward Peninsula.—Of the other gold-districts of the Seward Peninsula we know nothing from personal observation. The Solomon river and Bonanza river region, east of Nome, is said to afford good prospects for gold.

The Golofnin bay district, still farther east, has produced gold in commercial quantities. Gold is said to occur on the rivers



of Norton bay, and also on the Unalick and on the headwaters of the Anvik rivers. To the northwest of Nome gold has been reported from the Cape York region near the Bering

straits The geographical position of these different localities suggests that they may belong to the same gold-belt. Our facts as yet are not sufficient to prove this, and it must be simply regarded as a working-hypothesis. Should subsequent development and investigation show that the gold of all these districts of the Seward peninsula is derived from the same series of rocks, the gold-mining-region will embrace an area of at least four or five thousand square miles. We do not wish to imply that if this proves to be the case, this entire region will contain workable deposits, but would simply regard it as an area worthy of investigation by the prospector.

Gold was first found on the Peninsula on Golofuin bay many years ago. The discovery in the Nome region was made on Anvil creek, September, 1898, by Messrs. Lindebloom, Lindeberger and Brynston. The season was then too far advanced to permit of any development work or extensive investigation, but there was considerable influx of miners from Golofuin bay and from St Michaels and Anvil creeks, and many of the adjacent streams were staked.

During the following spring (1899) the news reached the other mining camps of the Yukon, and during the summer and fall a general stampede to Nome took place. The beach-placers were discovered in July, 1899. Outside of Alaska the first news of these gold-deposits was received with considerable incredulity, for the public had been too often humbugged with reports of rich finds in the Territory, and on this account there was no large influx of prospectors from outside of the Territory. The splendid market offered at Nome for lumber, coal and provisions was neglected by the merchants and trading companies until late in the fall. When the steamers left Nome last fall, lumber was selling at from \$200 to \$300 a thousand, and coal at \$75 to \$100 a ton, and the price of provisions was in proportion.

During the early part of the summer of 1899, the development of the diggings was much hampered by lack of machinery and lumber, and hence the output is not nearly as great as it might have been under more favorable conditions. The beach-diggings, according to the rulings of the local federal authorities, were not allowed to be staked, and offered splendid opportunities for individual prospectors. Any one possessing a rocker

and a shovel was permitted to go to work, and the yield varied from \$10 to \$50 a day. On this account wages were very high, and it was difficult to get a miner to work in the gulch-diggings.

The town of Nome, which is the center of distribution for the region, is situated on the coast, at the mouth of Snake river. It is about 100 miles north of St. Michaels, and some 2700 miles by steamer route from Seattle. It has a population of several thousand, and is provided with newspapers, hospitals, city government, etc. The sanitary conditions left much to be desired, and during the fall of last year an epidemic of typhoid fever was raging.

The Nome mining region, as well as the others of the Seward Peninsula, is but a few miles from tide-water, and hence easily accessible. The open season extends from about the middle of June to the first of November, while during the rest of the year the shore ice, which extends out from the coast some 5 or 6 miles, prevents landings being made from vessels. Communication can, however, be kept up with the outside world during the winter by means of dog- and reindeer-sleds.

The chief disadvantage of the Nome region, compared with the other mining districts of Alaska, is the absence of timber. The supply of drift-wood, which is at present abundant along the shore, will soon be exhausted.

Another serious drawback is the difficulty of landing at Nome. There is no harbor, and vessels, on account of the shallow water, are forced to anchor half a mile or more from shore. Freight and passengers are landed by means of barges in the surf. Most of the barges were wrecked during the course of the summer and fall, which involved heavy losses to the steamship companies.

Notes on the Gold-Mines of Zaruma, Ecuador.

BY J RALPH FINLAY, COLORADO SPRINGS, COLO.

(Washington Meeting, February, 1900)

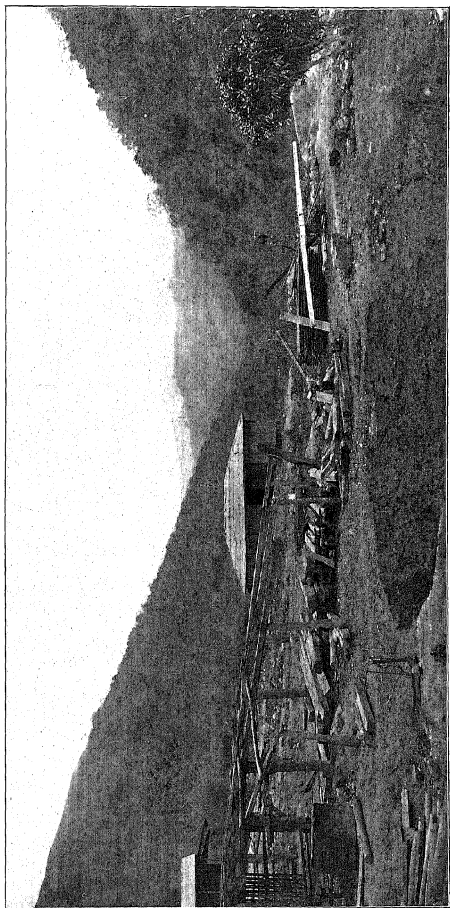
IN latitude 4° S, about fifty miles from the Pacific, and in the amphitheater on the west flank of the Andes, which is drained by the river Tumbez, is the ancient town and mining district of Zaruma. The town is picturesque in the extreme, perched on a ridge 1800 feet high, between two lovely mountain rivers, looking out upon neighboring hills and valleys clothed in rich green, relieved by many hamlets roofed in red tiles, and, at greater distances on all sides, upon mountain slopes of gloomy forest crowned by the bare summits of the Andes.

GENERAL DESCRIPTION.

The gold-mines, discovered in 1549, were worked extensively by the Spaniards in the 16th and 17th centuries, until their success was curtailed by the exhaustion of the oxidized surface-ores, and the uncovering of the refractory and hard ores underneath. The industry slowly declined until it was nearly or quite at a standstill in 1878, when an unfortunate English company, organized by Chilian promoters, acquired some of the best properties and began to work them. This company, after an extravagant *début*, relapsed into a struggle against poverty and mismanagement, and finally collapsed in 1894. In 1896 the English mines and many others, covering most of the district, were acquired by the South American Co., formerly the South American Development Co., of New York. (See Figs. 1 and 2.)

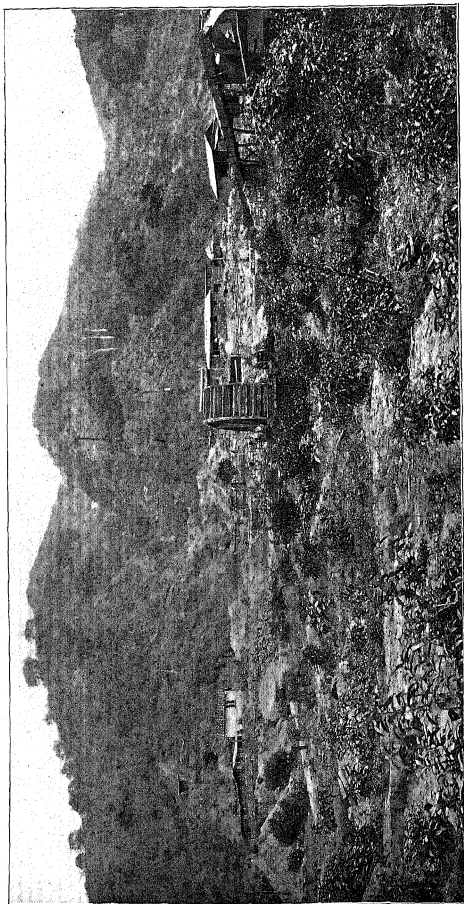
The vein-formation of Zaruma is extensive and complex, and the ores are somewhat refractory. In the immediate neighborhood of the gold-bearing veins the formation seems to be altogether volcanic, consisting of rather fine-grained holocrystalline diorite; but a few miles away, on either side, some gneisses and crystalline schists are to be found. About four miles south of the mines, and beyond some intervening granites, appear

FIG. 1.



View up the Valley of the Rio Amarillo from the Portovelo Mine. (The mountain in the background is the Cerro de Arcos, 11,000 feet above the level of the river.)

FIG. 2.



View of the Portovelo Mine, Zaruma, Ecuador, after its Abandonment by the English Co. (The gulch in the hill in front is a Spanish open cut on the outcrop of the Abundancia vein, or fault.)

unmistakable slates, which cover a large area still further south. The age of the volcanic mass is entirely unknown. It is quite probable that the diorites of Zaruma may be part of an ancient volcano, similar to that of Cripple Creek, Colo., but much larger.

The veins thus far opened in the main workings are three in number, and each is radically different from the others in direction, filling and appearance. One vein, known as the "Porto-velo," is composed almost wholly of calcite. Its trend is nearly north and south; its dip, 65° E. It contains, in the calcite, a very small percentage of iron pyrites, which gives the ore a cloudy appearance. The walls are not well-defined, and are "frozen" to the vein, which frequently contains large bunches of rock.

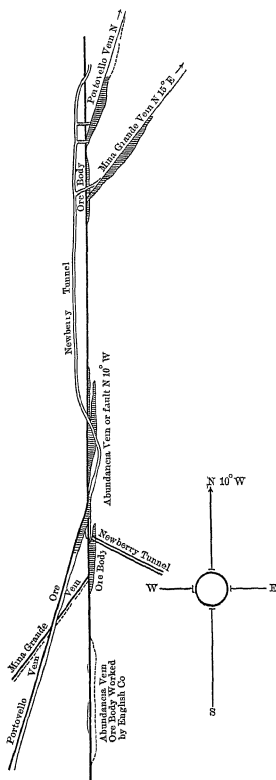
This vein is faulted (see Fig. 3) by the "Abundancia" vein, the displacement along the latter being not less than 1100 feet. This fault is strongly mineralized, and carries three large ore-chutes. One of them, worked by the old English company, is entirely south of the present workings. The other two are opened to some extent in the Newberry* tunnel. The middle ore-chute, where first cut, was 26 feet wide. The northern chute is 400 feet long on the tunnel-level, and, at its maximum, 24 feet wide.

This Abundancia vein courses N. 12° W. and dips 70° E. The vein-matter is almost entirely white quartz, rendered cloudy throughout by quantities of fine pyrites, and giving place along the hanging-wall to large bunches of heavy lead and zinc sulphide. As might be expected from so extensive a fault-plane, the foot-wall carries a very heavy gouge or fluccan, sometimes 3 or 4 feet thick.

The Abundancia cuts still another important vein, the "Mina Grande," which has a strike of N 15° E., a vertical dip, and a vein-filling made up much more largely of heavy zinc and lead sulphides than either of the other two. This vein is beautifully banded, and has a well-defined foot-wall (so called, the vein being vertical); but on the hanging-side it seems to grade, to a certain extent, into the rock. It is a very strong vein, in places over 20 feet wide. The length of the ore upon it is not

* Named after the late Mr W. E. Newberry, manager from 1896 to 1898.

FIG 3



Sketch showing in Plan the Ore-bodies in the Portovelo Mine (Two great veins, the Mina Grande and the Portovello, are faulted by a third, the Abundancia)

yet determined, but one chute has been followed for more than 300 feet.

The relation between the Mina Grande and Portovello veins,

ie, whether or not one faults the other, has not yet been determined. They are both faulted by the Abundancia for not less than 1100 feet horizontally, with an actual movement of at least 600 feet.

It seems very probable that both the Mina Grande and Portovelo veins have undergone a certain amount of enrichment, where intersected by the Abundancia. This is especially true of the Portovelo vein, which, at a distance from the fault, seems to carry only \$4 to \$8 per ton, but near the fault carries as high as an ounce to the ton in gold, for considerable distances.

Six ore-bodies have been already opened on the fault-vein and the intersected veins, and probably another will be added. These all lie within a length of 2500 feet, and each is, at a maximum, over 20 feet wide and from at least 100 to 400 feet long. The ore mined thus far (now nearly 40,000 tons) has averaged, without any sorting, more than \$15 a ton in gold. The veins promise to hold out well in depth, for some of the best ore-bodies have been opened in the tunnel, 700 feet vertically below the outcrop.

It must be remembered that these explorations cover but a small fraction of the district. An almost continuous line of old workings indicates that similar ore-bodies will be found for at least two miles further north and, at much wider intervals, for six miles beyond that. So steep is the rise of the mountains that the tunnel, if continued for two miles, will be 2500 feet below the surface.

Mining in Zaruma presents the ordinary difficulties of a Spanish-American country—lack of labor, enterprise and supplies. Neither of these is by any means insurmountable, but, taken together, they render the installation and operation of a large mining plant an affair requiring much money and patience.

I shall not attempt to describe in this paper the operations in detail, preferring to confine myself to an account of two features of special interest, namely, the somewhat novel method of mining adopted by the present company; and secondly, the method of bringing down timber for the mill. It is only fair to say that our lumbering-schemes proved on the whole a failure; but they were none the less interesting.

METHOD OF MINING.

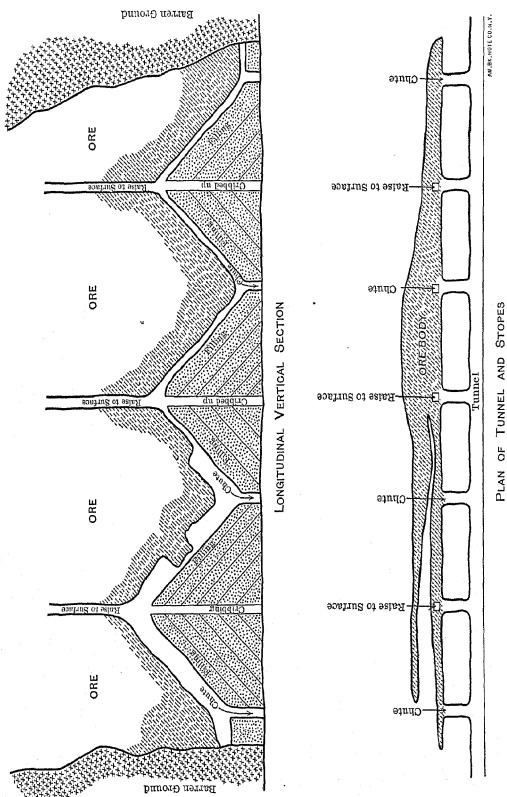
The first ore-body opened by the present company was on the "Abundancia" vein. The ore was not very hard, except in spots, and was accompanied by an exceedingly soft and treacherous foot-wall. It was evident that, whether timber were used in the stopes or not, they would have to be filled with rock. The only other alternative was to slice the body from the top downwards. Indeed, the latter method may yet have to be adopted near the surface; but it involves great difficulty in keeping open the raises, which are invaluable, both for ventilation and for furnishing future rock-filling for the lower levels.

The method of mining actually adopted (see Fig. 4) was essentially the filling-system used at the "hard ore" mines of the Minnesota Iron Co., at Tower, Minn., with the single exception that the fills, and of course the stopes, were made sloping instead of horizontal. In the first ore-body attacked, three raises, each from 200 to 300 feet high, were made along the foot-wall to the surface, coming out at the bottom of the deep open cut of the old Spaniards, from the sides of which any quantity of rock could be "milled" down into the mine at a nominal cost.

These three raises were 130 feet (40 meters) apart. The tunnel was run, not in the vein itself, but at a safe distance (about 20 feet) in the foot-wall. Cross-cuts were driven to the vein every 65 feet (20 meters), so that there was an entrance to the stopes at each of the raises, and also midway between them. Stopping began by cutting out the vein to its full width, and about 8 feet high, on the main level. Tracks were laid in the cross-cuts between the raises. When the bottom was cut off, the vein was also beaten away as far as could safely be done at the bottom of the raises. Then a lot of rock was thrown down each raise, which nearly filled the openings thus made. This filling was allowed to lie nearly at the angle of repose; and upon the sloping sides of the pile slabs were laid, to keep the ore from mixing with the rock. Then another slice was taken off as high as safety permitted, and the operation was repeated. Cribbed man-ways were, of course, carried up through the filling, to preserve the raises for future use. The slopes on each side of the filling-raises soon came together, half-way between the raises, or at the intermediate cross-cut. At these

points, chutes were put in and carried upward by cribbing as the stoping and filling proceeded.

FIG. 4.



This method of mining has the following advantages:

1. It requires but little timber—an important consideration where timber is scarce.

2. It allows of filling and tramming without re-handling, and, therefore, at a minimum expense

3. It allows the fill to be made very close to the back, because it is not necessary to leave standing-room on the slope for men to stow the dirt. This is a very important consideration where the walls are soft.

The system works well. The slope-filling feature of it was invented by Mr. Thomas Huddleston, at present mining captain on the property. The ore costs, for labor, supplies and superintendence, about 70 cents a ton, delivered at mill. This figure relates only to the operation of the stopes, and does not include the large amount of development-work done.

LUMBERING.

When it was decided, early in 1898, to build a 20-stamp mill for the mine, we were confronted by the following circumstances

Theretofore nearly all the timber for the mine had been delivered by two native contractors or *empresarios*, Miguel and José Santos Zambrano. These brothers were hard-working and enterprising land-owners, living on the edge of the forest, some miles away, who owned timber-lands, oxen, mules and peons. (The latter are practically slaves, being held to pay, in labor, at a rate which renders complete payment almost impossible, debts owed to their masters.) The method used in getting timber by the natives is the following:

The buyer gives to the contractor a list, showing the number and exact sizes of the pieces he wants. The contractor then takes his peons into the woods, and hews his timber to size. If boards or planks are required, they are sawed by whip-saws on the ground. Each piece of squared timber has a groove (*golleta*) cut around it at one end, by which *vetas* or cords of twisted raw-hide are attached for hauling; the groove being intended to prevent slipping of the *vetas*, as well as to protect them from wearing against the ground. Light timbers are dragged on the ground to the mine by mules, heavy ones by oxen, harnessed by means of a yoke lashed to their horns. Planks are carried by mules, being tied to the pack-saddle, one on each side of the animal, in such a way that the rear end drags lightly on the ground. The result is that one end of each plank always arrives considerably worn.

This method had seemed to us Americans utterly barbarous, and when we came to study the question of getting timber for ourselves, it was with the idea of adopting at once a very different method; but after a solid year of hard experience, we were glad to let the brothers Zambrano bring timber in their own fashion.

We were forced to undertake some new method, in order to secure a much larger amount of timber than we had been getting, because the Zambranos had not completely filled their contracts the season before, and now, owing to some family quarrel, the two brothers refused to co-operate, and confessed themselves utterly unable to bring down the considerable amount of heavy timbers needed for the mill. At the time of the year (January and February) when we made our investigations, we were in the height of the rainy season. The native roads were almost impassable with mud, and the project of dragging heavy timbers over them within a reasonable time seemed quite impracticable. So we turned our attention to a plan of floating timber down the Amarillo river, which flows by the mine. Nevertheless, in order to guard against the possible failure of this scheme, we determined to aid the Zambranos by furnishing them with money to extend and repair their roads.

The nearest timber accessible from the river was from seven to ten miles up-stream, on the bottom-slopes of the great amphitheater cut by the river in the flank of the Andes, which there rise like a giant wall, with an abrupt and almost unscalable ascent of 10,000 feet above the valley. On the steep and dripping sides of this gloomy amphitheater, where the rain is almost perpetual, clings a forest, in which the trees are mostly small and worthless, but which impresses the beholder with a sense of almost terrifying grandeur.

In this amphitheater the river is formed by the waters of three smaller streams. The united torrents have a flow of from 150 to perhaps 20,000 feet per second. From the junction to the mine the river has an average descent of 85 feet per mile, but above that point the smaller streams have a grade of perhaps 4 per cent. When swollen in the rainy season, they look like ribbons of snow as they lash about in their beds of gigantic boulders, but the amount of water is so considerable

that experiment proved it to be possible, by means of much hard work, to get logs down them.

Accordingly, we began to work in the woods with great hopes of success. We tried first to do things in American fashion. For instance, we thought it mere waste of time to square the logs; so we tried to haul them with the bark on, without *golletas*; but a thorough trial proved that the bark increased the friction on the ground so much that the cost of removing it would be repaid, many times over, by the greater ease of hauling thus secured. The same conclusion was reached with regard to the grooves (*golletas*); for we found that a rope or chain around the log, unless sunk in a groove, caused great friction in hauling. Moreover, we finally came to pointing the ends of the logs, in order to prevent them from catching on stones and snags.

Later on, we tried to build an American "travoy" road, supporting one end of each log on a small sled, and improving the road by laying poles or "skids" across it, to keep the logs off the ground. This scheme proved a disastrous failure. The "travoy," though made very light, were of doubtful value in hauling the logs down, while the labor of dragging them back again was trying to the oxen. The reason was that the oxen were yoked by the horns in a very uncomfortable position, and, to relieve them of this discomfort, the drivers always unyoked them on the return trip. When it was necessary to drag a travoy, this could not be done.

In short, experience taught us to have more and more respect for the methods of the natives; and at last we were thoroughly convinced that it was more economical to follow their ways entirely in doing work in the woods. The example of our energy and enterprise, however, was of great benefit to them, for they learned from us to plan their work in a more comprehensive manner. The Zambranos, put on their mettle by our competition, and aided also by the company in some matters, put aside their differences, and one year after our appearance in the lumber-business, they were in a position to supply all the timber needed by the mine.

Our hauling was only from the woods to convenient places on the banks of the river, down which we had to drive the logs from 6 to 9 miles. This work was very laborious, difficult and

dangerous While free in the current, a log would be carried with great swiftness, but sooner or later, according to the height of the water, it would be stranded or pinned against some rock in mid-stream Our first drive of logs was "hung up" altogether by the rapid lowering of the river

We arranged a diagonal boom across the river, near the mine, to guide the logs into a "pocket," made by running a diagonal line of strong tripods, floored and weighted with stone, some distance from one bank of the river. This arrangement worked very nicely at moderate stages of high water; but, during the rainy season of 1899, we unwisely put off driving down our logs until the heavy rains began, when the river rose so rapidly that it reached an extreme and unmanageable stage while the timber was still in the river As a consequence, our boom and tripod were overpowered, and, during two sudden freshets, some two thousand fine logs were swept over them and lost

REMARKS.

A word about Ecuador and its people may perhaps be of interest. The republic frankly admits itself to be the most backward in South America; and I suppose no foreigner would question this statement The population is very mixed. On the high plateaus of the interior, the bulk of the people are pure Quichuas, or Indians of the old Inca empire. They are industrious, peaceable and docile, but their imagination is so limited and their whole intellectual make-up so rigid and impervious, that it is difficult to conceive how they ever made even the moderate advances toward civilization with which they are credited. Their sole motive of conduct seems to be custom. The following story is characteristic An Indian woman carrying some eggs many miles to a town, to sell them at the Sunday market, met a foreigner who did not want to travel to the town for provisions, and was very eager to buy the eggs The woman refused, and the foreigner, after paying more than she asked for the eggs, took them by force. The poor woman burst into tears, saying, "Dear Sir, now I have nothing to sit down with on the plaza" In other words, it was her custom to sell her wares by displaying them in the plaza; and to do business any other way, however advantageous, was to her an unintelligible and distressing proceeding.

These people are valueless to the employer of labor, for the simple reason that they will not work, except in their accustomed pursuits

The small number of pure whites, of the Spanish race, who live in Ecuador, are likewise valueless to the employer, because they are too proud to do manual labor and too ignorant, except in rare instances, to be of use as agents

The mixed race, variously blended of white, Indian and negro, is almost the only material that the foreign employer can use. These people are neither so stupid as the Indian, nor so proud as the Spaniard, nor so lazy as the negro. They are often quite willing and companionable, though utterly ignorant of modern methods of work. They are also independent, in that each man is generally a cultivator of the soil, so that, while perfectly willing to earn a few dollars occasionally by working about the mines, they are not willing to depend wholly on that work. The result is that, in order to make miners out of them, a long period of patient and tactful encouragement is necessary

The question of labor is the gravest one that confronts the operator at Zaruma. Imported labor is apt to be extremely costly and inefficient. The climate is malarious, just at the mine, and for that reason it is hard to keep men there. The requisites for a successful manager are a knowledge of the language of the country, good judgment and tact in dealing with its people; youth; a good constitution and a good knowledge of the mining business—a combination not very easy to find.

Wages are about 50 cents per day (gold) for common labor; 60 cents to \$1 for native miners; \$1 for Jamaica negroes, \$2 for Italian miners. American miners and mechanics receive \$140 and upwards per month

The Coal-Fields Around Tsé Chou, Shansi, China.

BY NOAH FIELDS DRAKE, IMPERIAL TIENTSIN UNIVERSITY, TIENTSIN, CHINA

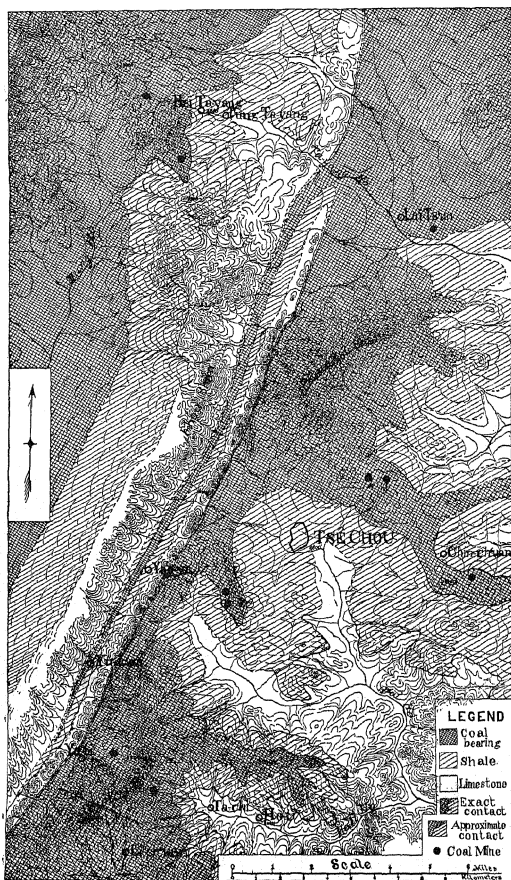
(Washington Meeting, February, 1900)

DURING July and August, 1899, the writer took advantage of an opportunity of going to Shansi to gather some information concerning the geology and value of the already famous coal-fields of that province. The long journey, mainly on slow river-boats, and the limited time at command, allowed only about ten days of work to be done in the coal-fields around Tsé Chou. The geologic structure and the rock-formations were found to be simple and quite regular, so that in that time the accompanying sketch-map (Fig 1) was made, and a fairly good idea of the distribution of the coal and general geologic features was obtained. The map was made by measuring a base-line about three-quarters of a mile long, triangulating for principal points over the field, and filling in the details by rapid sketches. The few elevations marked on the map were taken with an aneroid barometer. Only a few of the great number of towns and villages that are within this densely populated area are shown; and the coal-mines indicated are not the only ones within the area, but the ones where most of the following information about the coal was obtained.

The value of this coal-field was first clearly set before the scientific and commercial world by Baron von Richthofen,^{*} who made a geologic reconnaissance of Shansi in 1870. Since that time the hostile attitude of the Chinese government and people towards foreigners and their enterprises has kept the coal-fields from being developed. But the last few years of rapid change in the conditions of China have at last apparently opened a way for the exploitation of this coal-field. The Peking syndicate, a joint English-Italian company, now has concessions from

^{*} *China*, by Baron von Richthofen, vol. II. *Letters to Shanghai Chamber of Commerce*, 1870-1872, by Richthofen

FIG. 1.



Geologic and Sketch Topographic Map of the Region Around Tsé Chou, Shansi.

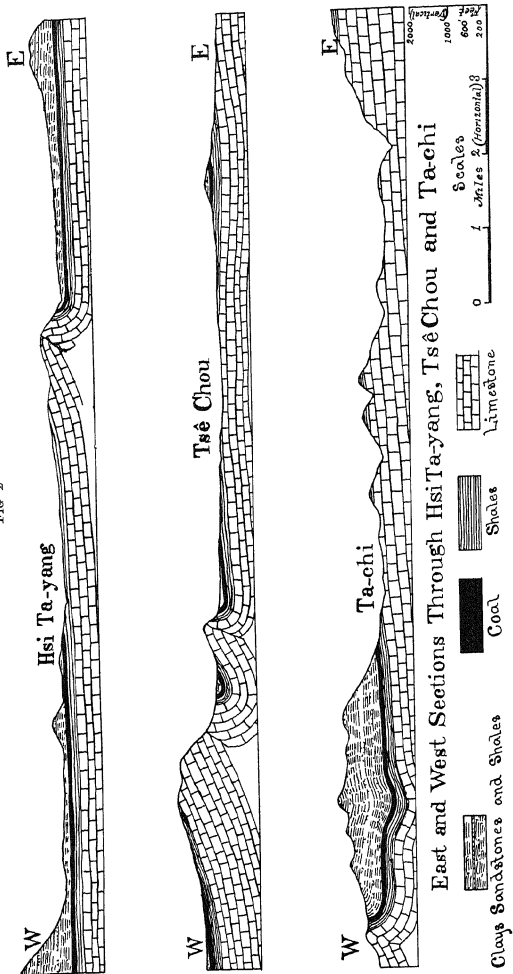
the Chinese government to work the coal of the Tsé Chou region, as well as most of the Shansi coal-fields.

The area shown in Fig. 1 lies in the southeastern part of Shansi, and is about 300 miles southwest of Tientsin, and 500 miles northwest by west from Shanghai. Tsé Chou, the principal city, lies in about $35^{\circ} 30'$ north latitude and $112^{\circ} 45'$ east longitude.

One going to Tsé Chou from Tientsin or Shanghai first passes over the broad, low-lying coastal plains of northeastern China and then on to a table-land, on which Tsé Chou is situated. These plains form a belt 100 to 300 miles wide, which extends semicircle-like around the west end of Shantung, from the Gulf of Pechili on the north to the Yellow sea on the south. Roughly speaking, the north and northwest boundary of these plains lies about 25 miles from the Great Wall and from Shansi. The rise in the plains from the coast-line to the mountains is very gentle. The edge of the plains north of Hwai-ch'ing is about 700 feet* above tide. Nearly everywhere the mountains and table-lands rise abruptly from the plains. This is especially true south and east of Tsé Chou, where the mountains rise bluff-like from the flat plains until a general elevation of about 3000 feet is reached. From this height a rough plateau extends towards the north and northwest across and far beyond the Tsé Chou region. As is shown by the map, the Tsé Chou region rather loses its plateau-features in the mingling of ridges, hills, narrow elevated valleys, and rough rolling lands. The ridges and broken lines of hills extend across the area in a N.N.E.-S.S.W. direction. Some of the hills, such as Fou-t'ou Shan, Pai-ma-ssü Shan and I-hou Shan, rise about 1000 feet above the general elevation of the country. The hills forming the broken ridge between Pai-ma-ssü Shan and I-hou Shan usually rise but 300 to 400 feet above the adjoining valley or rolling lands. For the most part the streams have not adapted themselves to the lines of hills, but have cut across them, thus breaking the ridges into numerous separate hills. All the drainage-streams of this area rise within it, and most of them, such as the Ho-ti Ho, the Pai Ho and the Ta-yang Ho, flow towards the southeast, and soon unite in the Tan Ho, which,

* This elevation should be considered as an approximation, since it was taken from aneroid barometer-readings, which were only roughly checked, some two weeks later, by readings at Tientsin.

Fig. 2



after about 20 miles more of a somewhat tortuous way, through a deep cañon, leads out upon the plains north of Hwai-ch'ing.

The rock-formations may be roughly divided into three groups, as shown in Figs. 1 and 2. These groups are as follows: A lower group of limestone, the *Kohlenkalk* of Richthofen, aggregating 2000 feet or more in thickness; a central group of shales, coal, sandstone, and a flint-bearing limestone stratum, aggregating about 300 feet in thickness; and an upper group of shales, clays and sandstones, which in this field exposes about 1000 feet of strata. These groups may be further divided, as shown in Fig. 3, which represents a generalized section, as follows:

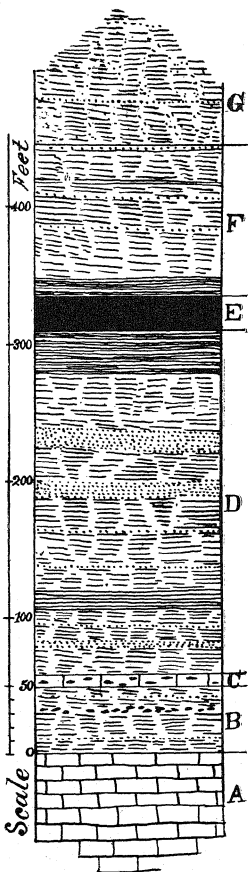
A, limestone, 2000 feet in thickness.

B, brownish clay-shales, usually with some sandstone, a little iron-ore and also a little coal, 50 feet in thickness.

C, massive gray limestone, containing numerous flint nodules and some fossils, 10 feet in thickness.

D, clay-shales and sandstones. The clay-shales usually become carbonaceous towards the top, until at the top there is usually 40 to 50 feet of black carbonaceous shale; 250 feet in thickness.

FIG. 3.



Average Section of Strata of
Tsé Chou Region.

E, coal, 22 feet in thickness.

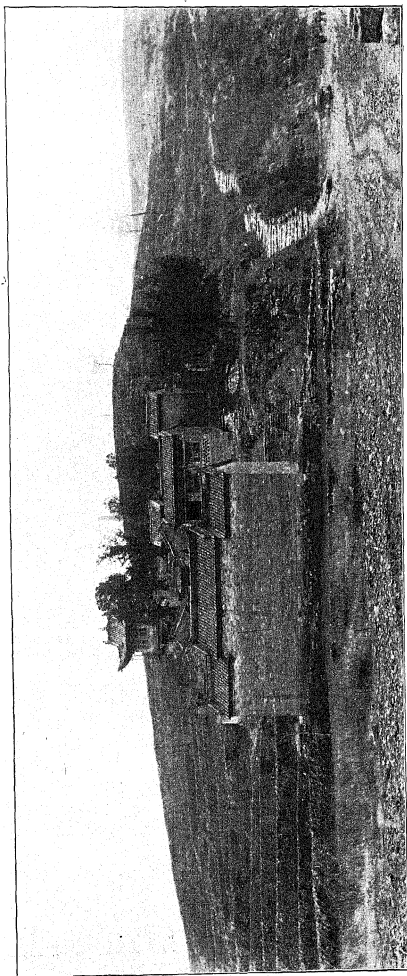
F, carbonaceous clay-shale and some friable sandstone-beds. The shales become lighter colored and less carbonaceous towards the top. At the bottom there is usually 15 to 20 feet of black carbonaceous shale, which graduates upwards into shales that are sandy and blue in color, and these in turn to sandy light-blue and yellowish arenaceous clays, 100 feet in thickness.

G, alternating beds of thick, yellowish, arenaceous clay strata, and usually rather thin, friable yellow, buff or light-gray sandstones, 1000 feet in thickness.

Over nearly all the valley and rolling lands there is a covering of loess which, in places, reaches 100 feet or even more in thickness. With the exception of this loess covering, this series of rock-beds is apparently conformable throughout. At any rate, that is the evidence gathered from observations within this district. As a whole, the rock-beds lie comparatively level; but there is some conspicuous folding and faulting. The axial lines of the principal folds and faults run about N. 25° E.—S. 25° W. A little minor folding runs at right angles to these. The mapped area, Fig 1, includes two large anticlinal folds and faults, with an intervening narrow synclinal fold and fault-block. The synclinal fold may be designated the Yu-k'ou syncline, because Yu-k'ou lies on it. The largest anticlinal fold and fault may be called the I-hou Shan anticline and fault, because it includes the I-hou Shan. This fold, as shown in Fig. 1, runs entirely across the mapped area, and elevates the strata more than 1000 feet. The next largest anticlinal fold lies on the west side of Fou-t'ou Shan and Pai-ma-ssü Shan, and extends nearly across the field, or from the southwest corner northwards to the Ta-yang Ho. It elevates the strata some 600 to 800 feet. The intervening fault-block and synclinal fold is from about $\frac{1}{2}$ to 1 mile in width. The faulting that accompanied each of these anticlinal folds was considerable, and resulted in raising the rock-beds on the west side of the fault-line considerably higher than those on the east side. The dip of the strata on the west side of the fold is very gentle compared to that on the east. These folds and faults give rise to ridges with steep east-facing slopes, and very gentle west-facing slopes. As a whole, the faulting and folding of this region has resulted in large areas where the strata dip very gently towards

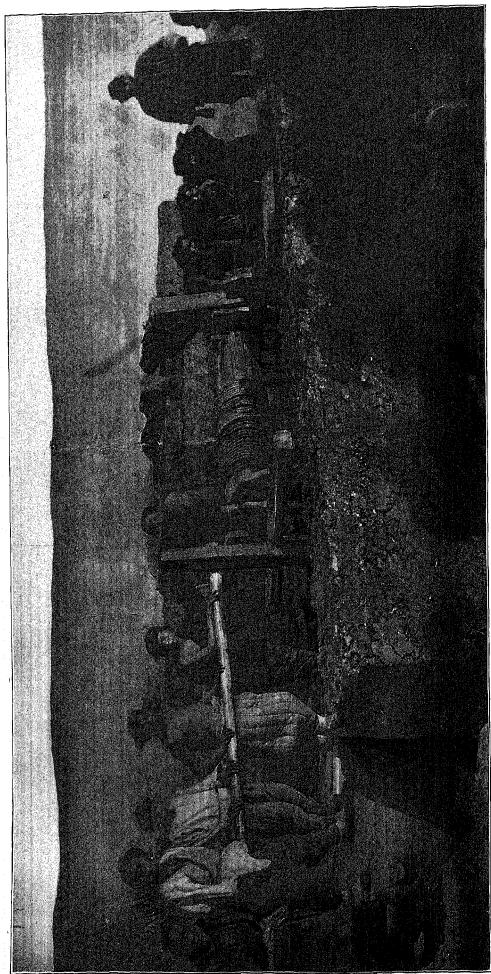
*

FIG. 4.



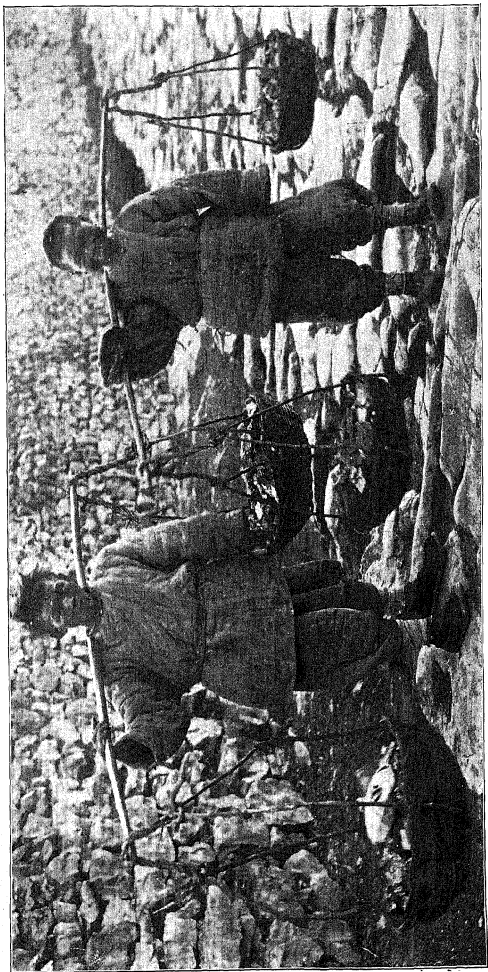
Terraced Hills along the Pai Ho, near Tsé Chou.

FIG. 5.



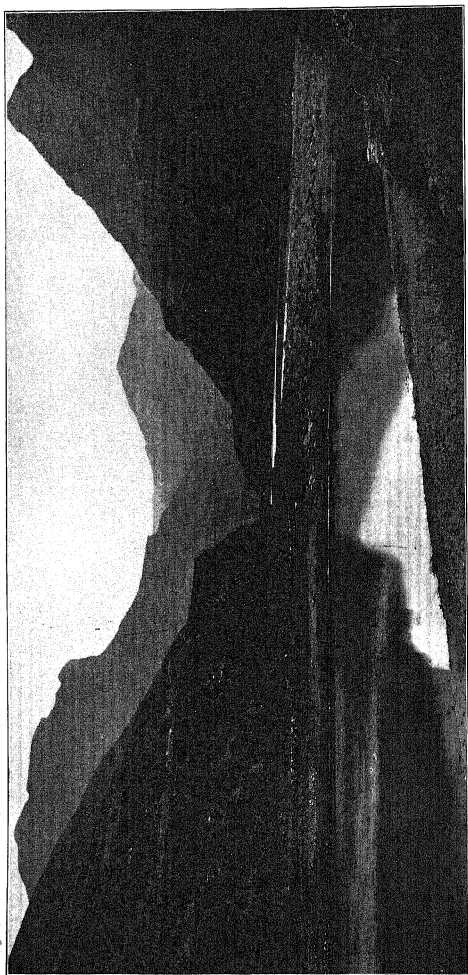
Hoisting Coal by a Windlass.

FIG. 6.



Coal-Carriers on the Trail between Tsé Chou and the Plains.

Fig. 7.



Canyon of the Tan Ho.

the W.N.W., and narrow belts where the strata dip rapidly towards the E.S.E. Where the faulting is great in comparison to the folding, which is usually the case, the belt of eastward-dipping strata is very narrow, and at places practically lacking. The large W.N.W.-dipping areas contain many little folds which rarely give rise to dips greater than 7° to 8° , while the average dip of the whole earth-crust block to the W.N.W. is probably not more than 1° to 2° . Practically, the only places where sharp folding will seriously interfere with coal-mining are the narrow belts along the Yu-k'ou syncline, and the east edge of the anticline that lines on the east side of the Yu-k'ou syncline. These places, however, are small and insignificant; and coal may not exist all along the Yu-k'ou syncline, as is indicated; for with the aid of observed structural suggestions most of it could be located there only doubtfully. The synclinal fold running W.N.W. by E.S.E. across the south end of Fou-t'ou Shan is only about $\frac{1}{2}$ to $\frac{3}{4}$ mile wide, and bends the strata down from the general level probably not more than 200 feet. It, therefore, affects only a narrow strip of the great coal-bearing bed underlying Fou-t'ou Shan, and is not so serious as is suggested by the section through Ta-chi (Fig. 2).

The workable coal lies in one bed about 250 feet above the flint-bearing limestone stratum. There may be a little coal, however, below this flint-bearing stratum, since some 15 to 18 miles S.S.E. of Tsê Chou, or near Hsiang Chuang, in the sides of the cañon of the Tan Ho, the Chinese are working a coal-bed that lies below this limestone stratum. According to the Chinese, this coal-bed is about 1 foot thick. Mr W. H. Shockley* also tells me that, in places in western Shansi, the principal coal-bed—an excellent one—is the one below this limestone.

In the Tsê Chou region the average thickness of the main or workable coal-bed is probably not less than 22 to 23 feet. At the mine about $1\frac{1}{2}$ miles west of Hsi Ta-yang, the coal is worked through a shaft 320 feet deep. Only the lower 10 to 12 feet of the coal is being mined. I had no opportunity to measure the full thickness of the bed, or to examine more than the part that is being mined. I was told by the Chinese miners

* Verbal communication

that the full thickness of the bed is 30 feet (Chinese), which is equivalent to about 36 feet (English). Parting streaks of shaly coal were rather common in the part of the bed that is being mined; but there is no waste coal taken out, and the average percentage of ash is probably not much, if any, greater than 10 per cent., which is about that given by the analysis of the piece of coal from this place.

In the coal-mines about $2\frac{1}{2}$ miles northeast of Tsê Chou, rooms are often opened in mining which expose the coal-bed from the top to the bottom. In two rather widely separated places in one of these mines, the coal measured 17 and 22 feet respectively. The lower 2 to 3 feet of the bed is composed of a friable earthy coal, above which the coal is remarkably uniform. Streaks of shaly coal, $\frac{1}{4}$ to $\frac{1}{2}$ -inch in thickness, are distributed every 4 to 5 feet through the coal-bed, and one layer of shale $\frac{1}{2}$ to 1 inch in thickness runs quite regularly through the bed some 6 to 7 feet below the top. In the other mine, which is about $\frac{1}{2}$ mile farther to the east, the coal-bed, at the only available measuring-place I saw, was 23 feet thick. In this mine the bed is quite regularly divided as follows: A lower stratum, 3 feet thick, of earthy friable coal, above which there is 14 feet of hard, firm, evenly good coal; over this 14 feet of coal there is about 1 inch of shaly coal or carbonaceous shale; and on this shale there is 6 feet more of good, firm coal, making in all 23 feet of coal.

In the coal-mine about $1\frac{1}{2}$ miles W.N.W. from Ta-chi, I saw only the upper 15 feet of the coal. The Chinese miners told me that the bed there is 20 feet (Chinese) thick, which is equivalent to about $23\frac{1}{2}$ feet (English). The coal that is being mined from this place, as well as that from near Ya-ti, on the west side of Fou-t'ou Shan, is wonderfully bright and glossy throughout. It breaks with a conchoidal fracture, and is so free from dust that it can often be handled without soiling the hands.

There is no waste material in the coal-bed in any of the mines; and, as shown by the sketch-map (Fig. 1), fully half this area is underlaid by this bed. If we take 22 feet as the average thickness and 1.5 as the average specific gravity of the coal, there are about 3,000,000,000 metric tons of coal within the 150 square miles, which is about the amount of coal-area in-

cluded in the map. It must be remembered that this area is only a little of the ragged edge of the great coal-fields of Shansi. Most of Shansi has been found underlaid by large coal-beds.* Richthofen estimates that the anthracite coal alone of Shansi amounts to 630,000,000,000 tons, and that the coal area of Shansi is greater than that of Pennsylvania.† The excellent quality of the coal is shown by the following table of analyses

Table of Analyses of Some Shansi Coals.†

Specimen Number	Locality of Coal-Mine	Water	Volatile Hydrocarbons	Fixed Carbon	Ash	Sulphur	Color of Ash	Remarks
1	1½ mi W of Hsi Ta-yang	1.55	5.55	82.74	10.15	0.25	Light gray	Average sample
2	2½ mi. N E of Tsé Chou	3.54	3.84	85.99	6.61	0.32	Cream-buff.	Sample of the best coal from this mine
3	2½ mi N E of Tsé Chou	1.95	3.59	80.86	13.58	0.35	Light gray.	Sample of the poorer coal from this mine
4	1½ mi. W.N W from Ta-chi.	1.95	3.37	80.44	14.22	0.34	Light gray	Sample of the poorer coal from this mine.
5	1½ mi W N W from Ta-chi.	2.26	2.23	88.56	6.93	0.40	Light gray	Sample of the best coal from this mine
6	1½ mi W.N W. from Ta-chi	2.75	2.61	86.09	8.53	0.31	Light gray	Average large sample
7	Foot-hills north of Ch'ing hua	1.84	3.11	87.63	7.41	0.54	Buff	Chance specimen
8...	Ping-yao, Ping-yang Fu district, South-western Shansi	0.49	17.81	57.70	23.98	2.80	Light gray	Chance specimen Coked in the crucible

All the coal of the Tsé Chou region is anthracite; its average specific gravity is 1.5; and it is hard enough to support any weight that might be put on it in the blast-furnace. The percentage of sulphur is uniformly low, and that of ash is comparatively so for anthracite coal. Some of the coals, however, will run rather high in ash, so that the bed, as a whole, would probably give not less than 10 per cent. of ash. The coal near Ta-chi and that near Ya-ti, or the part underlying Fou-t'ou

* Richthofen's *China*, vol 2, also his *Letters to the Shanghai Chamber of Commerce and Atlas von China*, also C. D Jameson, *Eng and Min Jour.*, vol lxxi, pp 365-367.

† *Letters to the Shanghai Chamber of Commerce*, p 29

‡ The analyses were made by N. F. Drake

Shan, will, very likely, not average over 8 per cent. in ash, for at those places the proportion of inferior to good coal is very small. Sample No. 6 was a large piece, which apparently represented the general average of the coal from the Ta-chi mine. Samples Nos. 7 and 8, from the foot-hills north of Ching-hua and from Ping-yao, or southwestern Shansi, were handed to me by Mr. C. D. Jameson, a member of the Peking syndicate, who said these samples were pieces that happened to be left behind, in shipping some of these coals away from Tientsin for the syndicate. Since they are chance samples, they could not be relied upon as representing the average coals from those places. They are interesting, however, as giving further evidence of the high quality of the anthracite in and near the Tsé Chou region, and as showing the bituminous nature and coking-qualities of the coal from the Ping-yang Fu district of southwestern Shansi.

The iron-ore, included in Fig 1, lies in the north half of the field. The part that is now being worked for iron-ore is a strip 1 to 2 miles wide, on the west slope of the I-hou Shan anticline, from near I-hou Shan to the north boundary of the field. The ore is hematite, and occurs as scattered nodules in a sandy clay stratum, below the flint-bearing limestone bed. From cursory examinations of outcrops, the iron-ore-bearing stratum appears to be from 2 to 3 feet thick. The present mine-workings are limited to this narrow strip, because there the ore-bed lies at shallow depths, so that it may be mined by open pits; whereas, over other parts of the field deep shafts and long tunnels would be required. The limited amount of ore, however, will probably never justify extensive mining over the area where it lies deep below the surface. This district has long been one where iron-ores were smelted, as is shown by the large heaps of furnace-slugs at a great number of the villages.

The natural resources of this area are not confined to the coal and iron-ore. Fire-clays of good quality for manufacturing brick and cheap pottery are abundant. The Chinese now use considerable quantities of these clays for making cheap soup-bowls, tea-pots, and various other kinds of pottery.

Sandstones occur in abundance; but they are too friable to be durable for structural purposes, although the Chinese have used them considerably for stone bridges, houses, monuments, and road-paving.

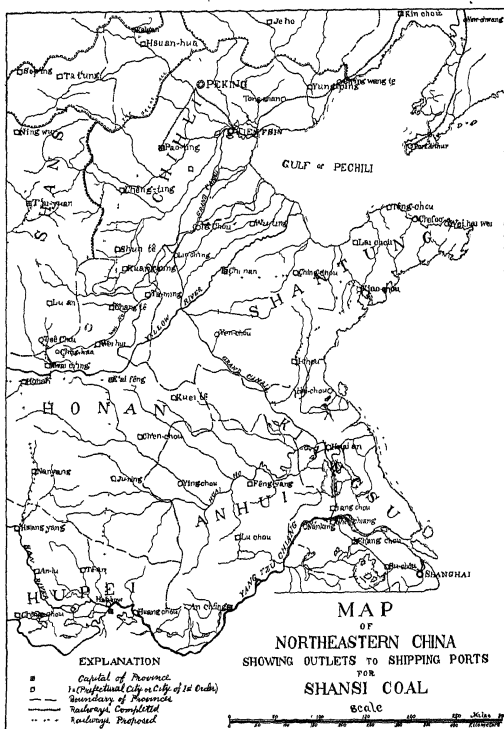
Massive limestones occur in great abundance, and of good quality for building-stone, fluxing material, the manufacture of lime, and probably also of cement. The limestones vary in color from light gray to blue and almost black, and in crystallization from the amorphous forms to real marble. The marble and the black limestone, however, were seen only in the cañon of the Tan Ho, a few miles southeast of the area mapped in Fig. 1. The marble has a reddish-gray color and fine structure. The black limestone takes considerable polish, and is used by the Chinese for monuments.

The soils are largely *loess*, but some are residuary. In either case they are usually fertile. As shown in Fig. 4, the mountain-sides are so closely terraced, to reclaim little plots of ground, that there is not much uncultivated land, and a dense population is supported by the agricultural products. The industries of the district largely center around coal-mining, although mining and transportation are done in a crude way. Practically all the coal is mined through shafts, which vary in depth from about 50 to a little over 300 feet. A very little coal is mined through inclines, and none through tunnels. Yet some of the shafts are almost as long vertically as a tunnel would have to be horizontally, in order to reach the coal at the points where they have cut it. A probable partial explanation of this circumstance may be, that the inferior character of the coal along the outcrops of the bed causes the miners to sink shafts away from the outcrops. Or, it may be that the outcropping edges of the coal have been mined away during past ages, so that the Chinese are now discouraged in attempts to find the coal by tunnelling.

No steam is used for hoisting, nor are explosives employed in mining. The latter is done simply with pick and gad. The coal is hoisted by a windlass which is run by men. At the larger mines the windlasses are about 5 feet in circumference, and have at either end a crank, with a long arm, at which four or five men can work. (See Fig. 5, unfortunately made from a cracked negative.) About 300 pounds of coal are hoisted at a time in baskets. The coal is mined by running tunnels through the coal-bed from the bottom of the shaft, and at intervals along the tunnel-ways large quantities of coal are removed, leaving more or less circular rooms, from 40 to 50 feet in diameter. By these methods probably not less than 50,000

tons of coal are mined within this area per annum. For local use, the coal is carried away in little carts, drawn by oxen; but the greater part is taken down the mountains by pack-animals.

FIG 8



For this transportation down the mountains only pack-animals can be used, because the trails which must be used are very rough and steep. The distance by trail from Ta-chi to the

plains is about 20 miles. One of these trails leading down the mountains is shown in Fig. 6. They are from 12 to 14 feet wide, and paved with stone. By ages of use, these stones have been worn until their tops are smooth and spherical in shape. Some of the larger stones have broad basin-like depressions, while others have narrow holes, 4 to 5 inches deep, worn into them, where mules have continually stepped. Over these rough and steep trails there is, during fair weather, an almost continuous line of pack-animals passing to and fro; and most of these are employed in carrying coal. Mules, donkeys, and men, each loaded with his pack of coal, are all similarly employed at this work.

The present style of working the mines and transporting the coal presents a striking contrast to what might be done were modern methods used. The great thickness and the almost horizontal position of this coal-bed make it practicable, as suggested by Richthofen* for other Shansi coal-fields, to run long lines of railroad-tunnels through the bed, and load the cars in the mines for distant transportation.

Fig. 8 shows some of the proposed railroad lines leading from the Tsé Chou region to outlets on the plains and to shipping ports. Probably the first road to be built will extend from Tsé Chou down the cañon of the Pai Ho and the Tan Ho (see Fig. 7) on to the plains north of Hwai-ch'ing. Mr. C. D. Jameson, who has made a preliminary survey for a railroad over this route, says† that it offers no engineering difficulties, although it will be a rather expensive road to construct. The grade of the bed of these streams is a gradual rise from the plains to within 5 to 6 miles of Tsé Chou, where there is a water-fall in the bed of the Pai Ho, of about 40 feet. This short line of railroad (about 30 miles) delivering the coal on to the plains-country would alone supply an immense market. For more distant deliveries, and for exportation to other countries, long railway-lines and water-ways would be needed. The railway-line running south to Hsiang-yang would there meet water navigation to Shanghai. About 65 miles of railway, running from near Hwai-ch'ing to Wei-hui, would reach water navigation by the Wei Ho and the Grand Canal to Tientsin.

* *Letters to Shanghai Chamber of Commerce*, p. 34. † Verbal communication.

Gold-Ores of the Black Hills, South Dakota.

BY H M CHANCE, PHILADELPHIA, PA

(Washington Meeting, February, 1900)

PROBABLY no other prosperous mining district is so little known as the Black Hills. The name leads one to assume that the district is a rolling country, consisting of more or less insignificant hills. Nothing could be more untrue, as the Black Hills is an elevated region rising to heights of 7000 and 8000 feet above sea-level, and broken by deep gorges and ravines. It is, in fact, a mountainous country in all that that term implies; but the cañons and gorges are of such a character that the country is easily penetrated by railroad-lines, and good wagon-roads exist to-day, affording access to every portion of it.

Aside from the stampede to the Black Hills country in 1876, when gold-placers were discovered, and 15,000 or 20,000 people became infected with the mining fever, the region has never had a mining "boom"

Quartz-mining commenced in 1877 or 1878, and has been successfully prosecuted ever since; the output of gold steadily growing, until at present the yield is about \$7,000,000 annually.

This great production is about equally divided between two entirely different classes of deposits. The first class, comprising the so-called quartz or free-milling ores (of which the Homestake mine is the principal producer), are veins of generally steep dip, in the older metamorphosed rocks, and similar to the veins worked in other mining districts. The second class of mines is located in what is known as the "siliceous gold-belt."

THE SILICEOUS GOLD-BELT

This belt, more particularly to be described in this paper, lies in the immediate vicinity of Deadwood and Lead City, and covers an area 6 or 7 miles in length by 3 or 4 miles in width. The formation in which the siliceous ores are found is a nearly horizontal series of sandstones and shales, generally

referred by geologists to the Potsdam period. These shales and sandstones were not originally gold-bearing rocks, but they have been cracked and fissured in all directions, and through these cracks and fissures gold-bearing solutions have permeated the formation, giving rise to a series of ore-chutes of variable width and thickness, and so numerous that the formation is literally riddled with chutes of ore. These ore-chutes are usually horizontal, and commonly extend for considerable distances in nearly straight lines, following the lines of fissure through which the ore-bearing solution has found its way into the formation.

Within certain limits of the developed area of this formation the formation is so completely mineralized that it is next to impossible to sink a shaft more than 30, 40 or 50 feet, or to drive a drift, upraise or winze for the same distance, without striking ore. In other words, the uncertainty which usually attends prospecting for ores seems to be almost entirely eliminated, as ore is found in every tunnel or shaft.

Most of these ore-chutes yield ore ranging in value from \$10 or \$12 up to \$15 per ton; some average \$20 or \$25 per ton, others have been found ranging in value from \$30 to \$100 per ton; and the general average value of ore found in this formation is from \$12 to \$18 per ton. Of such ore, the quantity is at present incalculable, as will be understood when it is considered that we have here a formation, 300 or 400 feet thick, with ore-chutes and ore-horizons scattered through it from top to bottom, in some places close together, in others more widely separated; that this condition obtains over an area of say 4 miles long by 2 miles wide; and that the chutes are of variable width and thickness, so that, while it is not possible to make any statement as to the average width or average thickness, it is evident that the quantity of ore embraced within these limits is enormous.

This siliceous gold-belt of the Black Hills seems unique as a gold-bearing formation. I do not know of any other district in the world where such a series of deposits has been discovered. There is no other district, except, perhaps, the South African gold-fields, where shafts may be sunk with the certainty that here obtains of striking ore. This is so thoroughly understood by the owners of the reduction-plants that they have bought a large area of practically undeveloped

territory Claims, often entirely barren of all evidence of ore, have been purchased as confidently as coal-operators purchase coal-land, with the assurance that, while the coal may not be visible, it will be found beneath the surface. The district has not produced any great bonanza-mines. Some ore-chutes have been found, yielding many hundreds or thousands of tons of ore, ranging in value from \$50 to \$150 per ton, and, before the reducing-plants were built, some of this high-grade ore was hauled by wagon 200 miles for shipment to works in Colorado; but these are exceptional instances. Most of the ore available in this district ranges in value, as already observed, from \$10 up to \$20 or \$25 per ton.

REDUCTION-WORKS.

This belt now supplies ore to four reducing-plants, as follows:

1. The Deadwood and Delaware smelter, having a capacity of over 200 tons per day.
2. The Golden Reward chlorination-mill, with a capacity of about 180 tons per day.
3. The Horseshoe Mining Co.'s (Kildonan) chlorination-mill, with a capacity of 120 tons per day.
4. The Black Hills Reduction Co.'s cyanide-mill, with a capacity of 60 tons per day.

Reducing Processes—The ores of this belt are successfully treated by smelting, by chlorination, and by the cyanide process, and the ability to treat them successfully and profitably both by straight smelting and by pyritic smelting is demonstrated by the Deadwood and Delaware smelter, which uses both processes.

Cost of Mining and Treatment—The cost of smelting under the conditions obtaining in this district probably ranges between \$4.75 and \$5.75 per ton; the cost of chlorination is about \$3.50 to \$4.50 per ton, and the cost of treatment by cyanide is thought to be somewhat less, possibly \$3 to \$3.75 per ton. The location of reduction-works at a point where water-power might be used instead of steam-power would reduce the cost of treatment by the cyanide and chlorination processes about 50 cents per ton.

Notwithstanding the fact that ores can be treated at the low cost above stated, the metallurgical works charge for reduction

\$9 per ton, which, with the railroad-freight of 75 cents per ton from the mines to the works, brings the cost for freight and treatment up to \$9 75 per ton. Individual miners, and operators working in a small way, getting out but a few tons of ore per day, generally find that the cost of mining, including dead-work and improvements necessary from time to time, brings the cost of the ore, delivered upon the railroad-cars, up to about \$4 or more per ton. This, added to the cost of transportation and reduction, practically leaves no margin of profit on ores averaging less than about \$15 per ton. As the assay-returns from the reduction-works rarely show as large values as those obtained from assays of miners' samples, the miners of the district do not, as a rule, attempt to mine ore that does not show by their own samples an average value of at least \$16 or \$17 per ton.

Profits.—The owners of the reduction-works can profitably treat ores from their own properties that do not yield more than \$10 per ton. Now, it is precisely between these limits of \$10 and \$17 per ton that the values of the largest bodies of ore range, and there is in sight, in the district, probably five or ten times as much ore ranging in value from \$10 to \$17 per ton as can be found exceeding \$17 per ton. It is, therefore, self-evident that so long as the high treatment-charges obtain, mine-operators, in order to reap anything like the full measure of possible profit, must own and operate their own reduction-plants. This fact is now well understood by those familiar with the district, and is appreciated very fully by the owners of the several reduction-works already mentioned.

Area Already Purchased.—Probably two-thirds of the developed area within the limits of this siliceous ore-belt has already been purchased by the three great companies operating in the district, namely, the Deadwood and Delaware Smelting Co., the Golden Reward Consolidated Co., and the Horseshoe Mining Co. The plants of these companies were all started in a small way, from six to ten years ago, and, after more or less checkered careers, have solved the problem of the efficient and economical treatment of the ores, and have grown from small beginnings to their present capacity. From the very outset they have all been steadily enlarging their capacity and are still continuing to enlarge it; they have all been buying additional ter-

ritory, and are continuing to buy such territory when it can be purchased at what they regard reasonable prices, so that each one of these companies now controls a very large area of mining ground in this siliceous ore-belt.

What these companies have accomplished others may now duplicate without passing through the period of experiment and uncertainty which each one of these enterprises was forced to pass through before solving the problem of economic and successful ore treatment.

Railroads.—The district is well supplied with transportation-facilities by the Chicago and Northwestern and the Chicago, Burlington and Quincy railway-systems. Ample water for power and all other purposes is furnished by streams immediately adjacent to the mills and but a few miles from the mines. Water sufficient for chlorination or cyaniding is available at almost any point at which it might be desired to locate such works.

PRINCIPAL BLACK HILLS GOLD-MINING COMPANIES.

It should be plainly said, at the outset, that the history of all these corporations is not that of a search for gold-ore, but that of the effort to find a process of treatment for extracting the gold economically and efficiently. There has never been any question as to the quantity or quality of ores available; that has been obvious from the beginning.

In the free-milling gold-belt, the Homestake, Father de Smet, Highland, Deadwood, Deadwood Terra and Caledonia were all located on a belt containing an enormous quantity of low grade (\$4 to \$6) ore, and the problem was merely one of cheap mining and milling. This solved, the profits quickly mounted into millions of dollars.

In like manner, in the siliceous gold-belt an enormous area was known to contain vast quantities of \$10, \$15 and \$20 ore of a refractory nature, requiring chemical treatment or smelting. The problem was to find a cheap and efficient process for treating it.

The following sketch shows how four different processes—straight smelting, matte and pyritic smelting, the chlorination process, and the cyanide process—have been successfully applied to these ores.

These successes have been achieved only after years of costly and often disheartening experimental work. Plants were built, only to be torn down and rebuilt, superintendents were engaged, only to resign after ignominious failures, but, after an expenditure of hundreds of thousands of dollars, success finally brought its reward; and these corporations now measure their profits, not by thousands, but by millions of dollars. It is reported that the Golden Reward Co spent in this way \$250,000, the Deadwood and Delaware Smelting Co. \$500,000, and the cyanide-works \$100,000, before their respective processes were treating ore profitably.

These pioneers have now cleared the way for others. Experimentation with its vexations and costly delays is no longer necessary, and plants can now be built and operated with a full measure of profit from the outset.

The Homestake Gold Mining Co —In 1878 the machinery for the first 80 stamps of this company was made in San Francisco, and shipped by rail to Cheyenne, Wyoming, whence it was hauled by ox-teams to Lead City, a distance of 300 miles. Eighty dollars per ton was paid for the freight alone. Materials and supplies of all kinds were enormously high. Notwithstanding all difficulties, the Homestake Co. commenced paying monthly dividends in 1879; and it is said that not a single month has since passed without the payment of a dividend, the amount paid growing larger from year to year. The company is now working on the 800-foot level, and is said to have ore in sight to supply its mills for at least twenty years, at the present rate of about 2000 tons per day. The amount actually paid for the property and the installment of the mill is said not to have exceeded \$400,000, while the amount paid in dividends up to Oct., 1899, is \$7,933,750. The Homestake mills proper now have 400 stamps, the Highland mill has 140 stamps; and the Deadwood Terra has 160 stamps. These are all now under the Homestake consolidated management, and show a total of over \$13,000,000 paid in dividends, in addition to about \$3,000,000 expended out of the earnings in permanent improvements, and other large sums paid for the purchase of additional mining property.

The Deadwood and Delaware Smelting Co. was organized in 1889 by the Swift Bros., of Wilmington, Del., and Dr Franklin

R. Carpenter, who is their present General Manager. The project was purely experimental at the outset, the object being to demonstrate that the ores could be successfully reduced by pyritic smelting; and after two or three years of experiment they succeeded in treating these ores not only by pyritic but also by ordinary smelting methods. Since this demonstration the company has enlarged its plant year after year, until it is capable of treating about 250 tons per day, and produces about \$2,000,000 in gold per annum. In addition to the constant enlargement of the plant it has been steadily acquiring property in this gold-belt, until it now owns over 2500 acres.

It is reported, however, that this company spent about \$500,000 before it succeeded in perfecting its smelting-processes, so that the works began to show a profit over operating expenses.

The Golden Reward Consolidated Gold Mining and Milling Co. was organized in 1887, and undertook in 1890 to treat the siliceous ores by chlorination, which, at that date, was an experiment, pure and simple. After about two years of costly experiment, it was found that these ores could be so treated at a fair profit; and the company has been successfully operating the process ever since. Its chlorination-mill has been enlarged several times, and now has a capacity of about 180 tons of ore per day. For several years past the company has been buying mining claims in the siliceous gold-belt, and now owns about 1000 acres.

The Horseshoe Mining Co. (Kildonan Mill).—This is another successful concern, operating in the siliceous ores of the Black Hills. The capital invested by this company came from Montreal. The Kildonan mill is a chlorination-plant with a present daily capacity for treating about 120 tons of ore. It was constructed a few years ago as a smaller mill, and has been twice enlarged. The corporation has also acquired large tracts of mining ground in the siliceous belt, and now owns about 840 acres. The Kildonan mill was successful from the outset. Constructed after the Golden Reward had shown how chlorination should be supplied to these ores, it escaped the experimental period which was so costly to its predecessors.

The Black Hills Reduction Co.'s Cyanide Mill.—This plant was built about five years ago. It has gone through the same experimental stages as the other plants. As originally constructed,

it was insufficiently equipped with crushing-machinery. The best method of applying the cyanide process to these ores had to be learned by experience, and by trial and retrial of different methods, before success was finally achieved.

The plant has recently been running smoothly, with a capacity of about 60 tons per day, and at a cost said to be somewhat less than that of the chlorination-process.

The Smith Syndicate —Mr Frank C. Smith, for a time general manager for the Golden Reward Co., has recently formed a syndicate of Minneapolis capitalists to purchase ground in the siliceous gold-ore belt. They have bought about 100 acres of ground in this belt, and are now planning the erection of reduction-works.

In addition to these plants, there is a small cyanide-plant at Spearfish treating ores from the Ragged Top district, and there is a small mill at Garden City, where both the chlorination and the cyanide-process have been used

A New Method for Working Deep Coal-Beds.

BY H M CHANCE, PHILADELPHIA, PA

(Washington Meeting, February, 1900)

IN almost all coal-fields, the quantity of explosive gases given off by the coal increases as depth is attained, requiring correspondingly enlarged quantities of air to ventilate the workings properly, by diluting and carrying off the gas.

Again, with increased depth there is a corresponding increased pressure caused by the weight of the overlying strata Sandstone or slate, which would form a good roof for a coal-bed at a depth of 300 or 400 feet, may be unable to sustain the pressure of 800 or 1000 feet of overlying rock. Hence, in nearly all deep mines, the miner will generally describe the roof as "bad," although the roof-rock may be a firm slate, forming an excellent roof for workings of moderate depth, but unable to stand the pressure resulting from the weight of a great thickness of overlying rock

With increased weight of rock-mass above comes also

greater danger of a "squeeze," or general crushing-down of the pillars of coal left to support the roof.

The methods of development in common use do not properly provide for the necessary increase in ventilation, as the workings extend over a constantly enlarging area. Attempts have been made to use the "three-entry" system for this purpose, by driving the haulage-road of extra width, to secure additional cross-sectional area for it as an intake, and by driving two parallel openings, one on each side, for return-airways, but this system does not provide sufficient area, and involves large expenditures for timbering and maintenance of the wide haulage-road.

To reduce the cost of timbering and maintenance of the main haulage-road, it is evident that this should be driven as narrow as possible. When this is done, the roof will often stand for years without timbering; and even where timbering is required, a narrow road will cost far less for maintenance, and occasion fewer delays and accidents from roof-falls, than a wide one.

The system in common use is to drive the main haulage-road and its airway together, in advance of the development-work. If the coal to be developed is to the dip, this haulage-road becomes an inside slope; if to the rise, it becomes a plane; and if the coal is tolerably flat, it may be driven on water-level, or, across the dip, "on the face" of the coal. The gangways or entries, from which rooms or chambers are opened for the mining of coal, are driven on the water-line (or "on the butt"), being started away from the main haulage-road, to right and left, at intervals of 300 or 400 or more feet.

To prevent a "squeeze" from closing the main road, a thick barrier-pillar is left on each side of the main road and its airway, to separate these from the working-places.

As the workings extend, it soon becomes evident that the main haulage-road is not large enough to pass the required quantity of air into the workings, nor the airway large enough to return this air to the upcast. To increase the ventilation, the most obvious expedient is to use both haulage-road and airway as intakes, and to pass the air through the old workings back to the shaft;—and this is one of the plans most frequently adopted. But it gives rise to serious troubles, and, moreover,

does not solve the problem, for the proper control of the air in its passage through the worked-out territory soon becomes impossible, and, furthermore, the ventilation is reduced to two splits (one on each side of the main haulage-road), whereas, five or six splits may be necessary to ventilate the new workings adequately. This plan is open to the additional objection that a squeeze in the worked-out territory on either side of the haulage-road closes the return from that side, and completely cripples the system, if it does not necessitate a shut-down of the colliery and a re-modeling of the whole method.

The difficulty with all the systems in common use is that, as the haulage-roads extend to greater distances from the shaft, and more air is required to ventilate the constantly enlarging area, the quantity that can be circulated is (by reason of the increased friction) steadily diminished. It frequently happens, when gaseous territory is encountered, requiring more air than can be thus supplied, that the mine, or a part of it, must be abandoned until the gas has gradually "drained off."

Many plans suggested to meet these difficulties have had no more than an experimental application, on account, perhaps, not of defects in design, but of local difficulties encountered in carrying them out in practice.

It should be recognized at the outset that no method can be regarded as feasible or practical that involves extraordinary expense. Competition among coal-producers is always too keen to permit the adoption of any plan which cannot be executed as cheaply as those in common use. Most of the so-called improved plans for mining deep coal have been impossible of application because they have involved either increased first cost, increased cost of maintenance or increased mining-cost.

No suggestion will be accepted as an improvement over present methods that does not promise a reduction in the cost of producing coal. Such a reduction may be effected in several different directions. Thus, a new method might cheapen the coal

1. By enabling a larger area to be worked from the central or main hoisting-shaft, thus apportioning the first cost of improvements among a greater number of tons;

2. By increasing the percentage of coal mined from a given area, thus reducing the first cost, or purchase-price, of the the property, per ton of available coal,

3 By increasing the daily output of the mine, which may effect a great reduction in cost by apportioning the fixed charges,—taxes, rent, management, general expenses, foremen, repairs, etc,—among a larger number of tons;

4. By decreasing the cost of the dead-work;

5. By decreasing the cost of maintenance of gangways and airways;

6. By reducing the risk of accidents to miners and employees, and damages recovered by employees or their heirs, by reason of such accidents;

7. By reducing the risk of damage to the mine-workings by squeezing, roof-falls and explosions;

8. By increased efficiency of laborers and miners, due to improved conditions of ventilation and haulage-roads,

9. By lessening the delays and expenses incidental to roof-falls on haulage-roads;

10 By increased life of timber, due to efficient ventilation.

The cost depends largely upon the output, and any method by which the output is increased will effect a notable reduction in the cost per ton. Other most promising directions in which to work with a view to economy may be found in lessening the cost of dead-work, and of the timbering and maintenance of haulage-roads.

With these ends in view, the system now to be described has been devised, the aim being, (1) to enlarge the area that can be mined from a given shaft; (2) to increase the output; (3) to reduce the timbering required on haulage-roads and lessen the cost of maintaining these roads; (4) to remove the danger of closure of haulage-roads and airways by squeezing; (5) to provide adequate ventilation for emergencies, such as outbursts of gas, (6) to provide increased transportation-facilities, and (7) to accomplish these ends without incurring expense in any direction in excess of that of the systems in common use.

The plan is illustrated by the accompanying plate. The main haulage-road and its accompanying airways are driven ahead into new territory, and gangways or butt-entries are turned off, as in present practice, except that the haulage-road and airway are made as narrow as the width of the car will permit, that is, just wide enough to permit a man or mule to pass a car standing on the track, thus reducing the first cost of

timber and the cost of maintenance to a minimum, and greatly lessening the probability of roof-falls on these roads.

As soon as any gangway or butt-entry is opened, two rooms or chambers are opened on each side of the main road, and are driven up, parallel to that road, until they are holed through into the next gangway or butt-entry, as shown in the diagram. These rooms and chambers are driven wide enough to let the work be done at the prevailing contract-price, per car or ton, for mining coal. They are, therefore, in no sense dead-work.

The rooms nearest the main road are driven somewhat narrower than the outside rooms, and the latter may be very wide. Reasonably thick pillars of coal are left between each pair of rooms and the main roads, and between the two rooms of each pair. Beyond these outer rooms or chambers a thick barrier-pillar is left, one on each side, to protect these rooms and roads from the effects of a squeeze in the workings.

When these rooms or chambers have been connected, we have what may be termed a six-entry system, in which the four inside entries are all used as intake-airways, and the two outside entries as return-airways.

The two outside chambers or rooms give a large area for the return-air to find an easy exit to the upcast, and the inside chambers or rooms, in addition to their use as intake-airways, may be used as manways, one for each side. The miner can thus go to and from his work without crossing the main haulage-road.

In operating this system, the ventilation of each lift or panel should of course be kept entirely independent of other workings, a separate split being taken in on each gangway, passing under a bridge in crossing the return-airway, and, after being coursed through the workings of that lift or panel, brought back through the airway direct to the main return-airway.

If the inside rooms used as intakes require much propping to keep up the roof, the narrow road originally driven for an airway may be used as a man-way or travelling-way, instead of these rooms.

Should the output become too large to be handled on a single track, the narrow airway may be equipped as a second haulage-road.

This system secures always the main entrance to all parts of

the mine, and enables efficient ventilation to be maintained, even if a part of the mine become closed by a squeeze; for the main roads, intakes and returns are protected, and a squeeze will affect the ventilation of that portion only of the property over which the squeeze extends.

Should very gaseous territory be penetrated, or an outburst of gas occur at the face, this system gives facilities for concentrating almost the entire power of the ventilating-fan upon the danger-spot, and thus for passing enough air through to make the place safe, and permit work to be resumed and prosecuted.

The method involves no extra charge of any kind for dead-work, beyond that of the method in common use, it lessens the cost of timbering and maintenance of the main haulage-roads, enlarges the area that may be developed with a single plant, increases the number of working-places that can be kept in operation, augments the transportation-facilities; provides much needed travelling-ways; perfects the protection of these improvements from the possible effects of a squeeze, and practically divides the mine into two distinct halves, each with its independent airways and roads

The difficulties outlined above are now commencing to be felt in nearly all of our deeper coal-fields. We constantly hear of attempts to force more air through the growing workings of deep mines by the use of higher ventilating-pressures; and a demand has manifested itself for fans capable of being run at high peripheral speed, to produce a water-gauge reading much higher than that of from 1 to 2 inches, generally registered hitherto. It is, perhaps, unnecessary to point out the reasons why this is neither the most economical, nor theoretically the best, way to secure increased ventilation, or to describe the conditions that must always limit the improvement so gained to relatively small proportions.

Upon failure to increase the ventilation satisfactorily by higher fan-speed, and the enlargement of existing airways, resort is frequently had to the remaining expedient of sinking additional airshafts, to ventilate the workings farthest removed from the main shaft. This, of course, solves the problem; but in deep territory the cost of sinking such shafts is large, and materially adds to the mining-cost per ton

Gruson Rotating Turrets

BY T. GUILFORD SMITH, C. E., BUFFALO, N. Y.

(Washington Meeting, February, 1900)

IN presenting the subject of "Armored Turrets for Coast Defense" to this Institute, I am indebted to the Gruson Iron-works, a company incorporated under the laws of the State of New York, for valuable information, model and plans, by which I hope to make clear the construction and peculiar merits of this class of gun-protection.

I wish it understood, however, that this is not an undeveloped and untried inventor's ideal, but an advanced and fully perfected system, which has long since passed the experimental stage and has been adopted by most of the foreign governments, after years of extensive experimenting and the expenditure of millions of dollars.

The present seems an appropriate time to present the matter to the scientific public, since, for the first time, it is possible to produce these turrets in this country, of American material, and made by American workmen, owing to an agreement entered into between the Gruson Iron-works and the Fried. Krupp Grusonwerk, of Magdeburg-Buckau, Germany, where they have hitherto alone been manufactured. Although its full development and present perfection have been attained at the German works, it may be of historic interest to state that the first idea of using a rotating protected platform for large guns originated with Mr. Theo. Ruggles Timby, a native of the State of New York, who filed a caveat in 1843 for a "metallic revolving fort, to be used on land or water, and to be revolved by propelling engines located within the same and acting upon suitable mechanism." This was followed in 1862 by the issuance to Mr. Timby of two patents (No. 35,846 and No. 36,593) covering the ideas described in his caveat of 1843. The first practical application of this system was made on the "Monitor," of Civil War fame, Mr. Timby receiving \$10,000 for two

turrets as royalty for the use of his invention by John Ericson, to whom this construction is usually, but erroneously, ascribed.

The manufacture of Gruson armor has been closely watched by our government for the past fifteen years; its merits having been recognized in the official report of the "Endicott Board" made in 1886, in which the system is spoken of as being well adapted for the needs of our coast defenses at certain points. In the report of the "Board" (printed as Executive Document No 49, first session, Forty-ninth Congress) they say that the shore-batteries may be revolving turrets, and they recommend such turrets as a part of the proposed defenses of the ports of New York, San Francisco and Boston, besides Hampton Roads, Narragansett Bay and Key West. The report recommends at the above places the installation of nine 2-gun turrets for New York, five 2-gun turrets for San Francisco, four 2-gun turrets for Boston; two 2-gun turrets for Hampton Roads; one 2-gun turret for Narragansett Bay; and one 2-gun turret for Key West, making a total of twenty-two complete turrets.

Just before the publication of this report, a trial of Gruson armor was made by the Italian government at Spezzia. The trial-plate, weighing 193,895 pounds, was mounted against the solid rock, being flanked on either side by two junction-plates. It withstood four direct shots, at a range of 150 yards, from a 100-ton (16.93-inch) Armstrong gun, using Krupp steel projectiles; the result of the hits, which all landed in about the same place, being three abrasions, varying from $1\frac{1}{2}$ inches to 4 inches in depth, and a number of fine cracks on the surface, none of which, however, showed upon the rear of the plate. All of the steel projectiles were shattered into thousands of pieces.

At this trial representatives of the United States Engineer and Ordnance Corps were present, and the test was considered absolutely conclusive by all the official representatives of the great powers. Since then Gruson turrets have been purchased and erected by the governments of Germany, Italy, Austria, Holland, Belgium, Switzerland, Roumania and Brazil. Some time ago there was an interpellation in the British Parliament by one of its members, by which the government was asked why there had not been any tests in England of Gruson turrets, to show their capability of withstanding heavy fire with the

most approved modern ordnance and projectiles. The chief naval constructor answered. "We know enough of these turrets to say that where foreign coasts are protected by Gruson turrets British war-ships will not go."

During the late war with Spain there was not sufficient time to obtain these turrets from Germany and place them in position, but now that we are again at peace, and the importance of defending our coast from enemies has been so clearly shown, it seems opportune to call attention to the means of defense adopted by foreign countries, indorsed with approval by our own officers sent abroad for the purpose of investigation.

What are Gruson turrets? What do they look like? Of what are they made, and what makes the protection they afford so complete?

These questions can best be answered by imagining two big coast-defense guns, say of 12-inch bore, or perhaps even of 16-inch bore, such as the monster gun just completed at Watervliet Arsenal and soon to be tested at the proving-ground at Sandy Hook, in New York harbor. In the Gruson turret two such guns are placed side by side on independent carriages, and the latter are set up on a platform of steel construction with all the necessary apparatus for changing their angle of elevation, upon which depends the range, also for hoisting their ammunition from the bomb-proof below, for opening and shutting their breech and ramming in the ammunition. Imagine all this apparatus on a turn-table to allow the guns to send their fire in any direction by a simple rotation of the platform, and you can obtain some idea of the appearance and operation of the turrets. There is need of protection for guns and men, not only in front and on both sides but overhead as well; for the accuracy of modern naval ordnance permits of sending projectiles from considerable distances so aimed as to reach the point of delivery under angles from above, striking behind ramparts of earth or stone in such a manner as to destroy and dismount guns and any machinery connected with them.

Explosive shell and shrapnel can be fired so accurately, and their explosions in the air regulated so well, that they will burst directly over the heads of the gunners and hurl their missiles straight upon them. The Gruson turret, in exposed and well-

advanced positions, at or about the sea-level, furnishes abundant shelter from all these kinds of attack. It is shaped like the shell of a turtle, and is mounted over and around the guns and their men, leaving only two port-holes just large enough for the gun-barrels to protrude, and a small lookout in the top-plate for sighting them. This protective shell consists of a number of sectors, varying according to the size of the turret, forming the circumference of the flat dome or cupola, and two half-circular plates forming its roof, the sectors giving protection on the breast and the roof-plates giving protection overhead. The dome rests on a substructure made of steel plates and strengthened with angle-irons. Heavy steel beams run across this substructure to carry the carriages on which the guns are mounted. The substructure is further provided with a roller-path of cast-iron, resting on a number of conical flanged steel rollers, the axles of which have their bearings in a live ring which keeps them in proper relation to each other. The conical shape of the roller allows them to revolve, without the aid of a central pivot, on a stationary roller-path imbedded in the masonry.

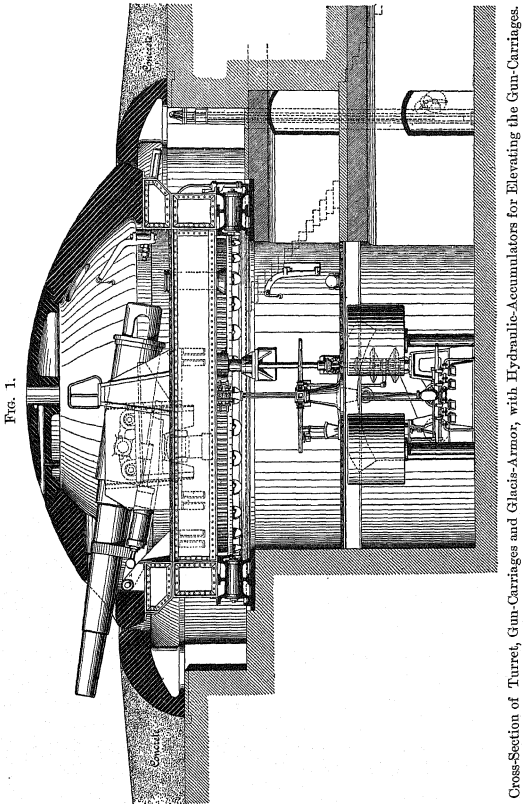
The cupola is surrounded by the so-called "glacis-armor" which forms a ring of double-curved chilled cast-iron plates somewhat similar to those used for the cupola, but which are set upon solid masonry, are stationary, and protect the substructure, gun-carriages, and the machinery by which the turrets and guns are operated.

The glacis-armor is itself further protected by a construction of granite and concrete. The cupola can be revolved either by hand-, steam-, hydraulic, electric or other motive-power, as may be most convenient.

To revolve the turret by hand a capstan is provided, which transmits its revolutions through gearing to a pinion and racer fastened to the upper roller-path. Turrets for the larger sizes of guns are generally revolved by steam-power, for which purpose a two-cylinder engine is placed in the lower gallery. The starting-lever for the engine is operated from the middle gallery. Both hand- and steam-power can be made interchangeable by suitable mechanical apparatus, thus providing against the contingency of the failure of either.

In order to stop the turrets from revolving spontaneously,

especially when the guns are fired singly, a suitable brake is attached to the substructure, consisting of hydraulic cylinders

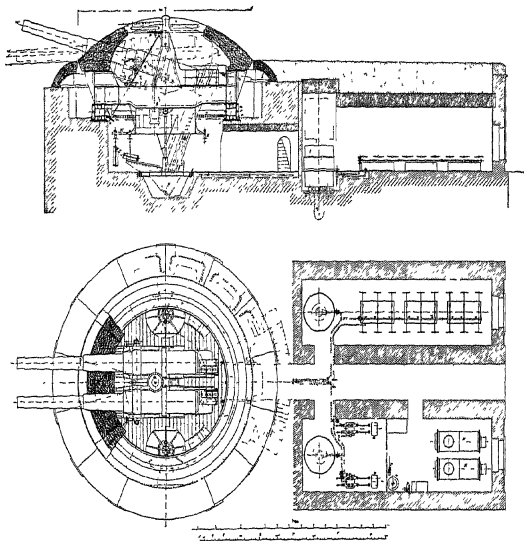


controlled by proper valves, whose pistons press against a brake-ring cast on the lower path provided for this purpose. Hy-

draulic cylinders are connected by pipes to a pressure-transformer in the center of the turret.

The dome is perforated by two port-holes through which the guns operate side by side, and which so closely surround them that no projectiles from the outside can penetrate into the interior of the structure. In order to make this possible, the

FIG 2.



General Plan and Elevation of a Turret to Contain Two 12-inch Guns, showing also Arrangement and Position of Pumps, Boilers, Rotary-Apparatus, Ammunition-Hoists and Auxiliary Machinery

guns are mounted on special carriages, technically known as "Gruson minimum port carriages," which provide for the elevation and depression of the guns from a pivot near the center of the embrasure, instead of having these movements take place on the trunnions of the gun. Such an arrangement makes it necessary to lift a considerable weight with every

change in the elevation of the gun, and for this purpose hydraulic accumulators are provided and supplied by a special set of high-pressure pumps.

The horizontal movement of the gun is effected by rotating the turret, the amount of such motion necessary to a proper sighting being regulated by the commanding officer, who has his station in the center of the cupola and makes his observations through an orifice in the dome or roof, in which is also provided a sighting-apparatus. A hoisting-and-charging mechanism is likewise provided, and operated by hydraulic or steam, as may be desired.

A reference to the illustrations will clearly demonstrate the general design and construction of the modern Gruson turret as now manufactured

Fig. 1 shows a cross-section of the turret, gun-carriages and glacis-armor, together with the hydraulic-accumulators for elevating the gun-carriages.

Fig. 2 is a general plan and elevation for a turret to contain two 12-inch guns, and shows, in addition to the above, the arrangement and position of the pumps, boilers, rotary apparatus, ammunition-hoists and auxiliary machinery.

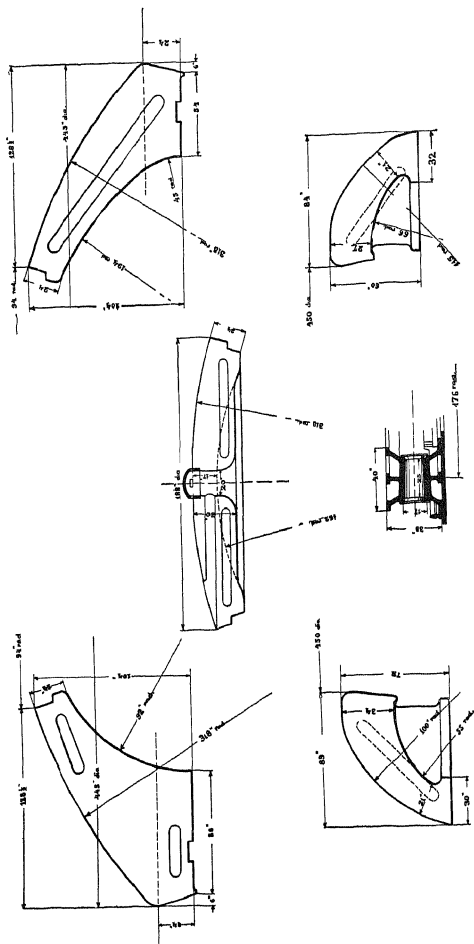
Fig. 3 gives detailed sizes of certain parts for the purpose of indicating the magnitude of the work. Some of the individual plates for a 16-inch turret will weigh about 90 tons, and great skill is necessary to successfully handle such a mass, with its subsequent special treatment and accurate machining. The revolving chilled cupola for a 12-inch 2-gun turret is composed of 14 plates having an aggregate finished weight of 1,667,000 pounds; the protecting stationary chilled glacis-armor being composed of 12 plates having a total weight of 1,175,000 pounds.

A cupola for a 16-inch 2-gun turret weighs 2,850,000 pounds and the glacis-armor 1,415,000 pounds.

The total finished weight of a 12-inch 2-gun turret, exclusive of the guns, is about 3,700,000 pounds, and of a 16-inch turret about 5,800,000 pounds.

The material used for the cupola and glacis-armor is a special quality of cast-iron, hardened by surface-chilling to a depth of $2\frac{1}{2}$ inches or more. The plates or sectors going to make up a complete fortification are double-curved and of varying thick-

Fig 3



Figured Details of Certain Parts, showing Magnitude of the Work

nesses, according to their location, and are held together by means of imbedded keys, no bolts or rivets being used

The great mass and weight of the Gruson turret precludes its use for ship-protection

When once established, the Gruson turret is easily maintained, owing to its simplicity of construction, its solidity and minimum risk of deterioration, and it requires less repair than any other kind of fortification, owing to the fact that the guns and carriages and interior structure are so thoroughly protected from the elements. In addition to this, it is the cheapest and most effective form of structure for gun-protection which can be adopted for low or advanced and exposed points, such as the entrance to the harbors of important cities, where high elevation cannot be obtained for the construction of the ordinary style of fortification

These turrets are not intended to take the place of any existing form of fortification where the nature of the ground renders such fortification sufficiently effective, but are for use especially in localities where it is necessary to fortify points at or about the sea-level, and where its form would render it inconspicuous and present a very small target to an attacking enemy; since it is possible to render it almost indistinguishable from its surroundings, especially in the absence of buoys, lights, ranges, and the ordinary aids to navigation which are removed in time of war

The Roller-Pallet System for the Manufacture of Bricks.

BY CLEMENS CATESBY JONES, B S , RICHMOND, VA

(Washington Meeting, February, 1900)

ONE of the achievements of the present century has been the development of brick-making from the crude and humble handicraft of the individual to a potential industry employing machinery, requiring immense capital, and now demanding that scientific direction which will finally raise it to the importance and dignity of a modern industrial process. It is as yet in the first stages of progress in this direction. The constant obstacle to a fully developed process has been the treat-

ment, by three separate and distinct operations, necessary to produce a unit of product—the single brick—having a weight of about 5 pounds, a mass of about 80 cubic inches, and a market-value of about half a cent. It must first be formed, then dried, and then fired. Since there is no possible means at present of accomplishing these results by a single continuous operation, it will be seen at a glance that the manual labor still indispensable constitutes the largest item in the cost of manufacture. While this applies especially to the common clay brick as a standard, the same conditions affect other clay products, such as pressed bricks of all descriptions, ornamental bricks, terra-cotta and fire-bricks.

When the market-value of a crude commodity declines to a point where the manufacturer can no longer produce it at a profit, the aid of labor-saving machinery becomes necessary, and the various phases of each manufacturing operation require systematic control. This necessity gradually extends from the factory to the field. The raw material, its extraction and preparation, then require attention. The scale of operation now demanded of the brick-manufacturer not only calls for an adequate and suitable supply, but the cheapest methods of mining and transporting clay. In addition to this, the thorough survey of unknown clay-deposits, with careful examination of the quality of their contents, is now recognized as of paramount importance. In other words, the whole art of brick-making will have soon passed from the manipulations of the mere artificer to the progressive systems of the chemist and the engineer.

The most successful modern plant will be that which is projected, designed, equipped and operated in accordance with scientific principles and methods. Such a statement sounds axiomatic. But, although brick-making has every appearance of being the simplest of arts (if not the original of them all), and hence capable of quick radical improvement by mechanical means, yet, in reality, development has perhaps been more retarded in this than in any other industrial branch. Undoubtedly, special machinery for particular operations has been brought to high effectiveness. Drying apparatus and improved kilns have been successfully introduced. Still the factor of labor has not been diminished proportionately, and frequently

an assemblage of the latest and best machinery and apparatus, while securing larger output and other advantages, has resulted in an increased cost of manufacture.

A truly successful industrial process should be as largely as possible dependent on mechanical means, and capable of operation without interruption. Heretofore there has been, in brick-making plants, no combination of special mechanical devices thus permitting continuous operation. Hence every interruption (which means a point at which manual labor intervened) contributed to an aggregate manufacturing cost almost comparable with that of the crudest manual methods. The explanation of the slow mechanical advance of brick-making to the rank of a process lies, I think, in these few, simple causes, the reasons of which will be discussed further on. The importance of a suitable mechanical system eliminating these defects will be better appreciated through a brief account of prevailing industrial conditions and practice. For such an account, the fundamental fact is that nearly three-fourths of the cost of manufacture of bricks to-day consists of labor alone. So far as I am aware, this disproportion of labor-cost to the value of either raw material or finished product is not equalled in the production of any other commodity.

The magnitude of the brick-industry in the United States may be measured by the value of the output for 1898, which was \$57,644,706. Various attempts have been made to establish a coefficient of consumption of bricks *per capita* of population, but they are more or less fallacious. The consumption of bricks in New York City is very close to 1,000,000,000 per annum. Of this number about 900,000,000 are now annually produced in the Hudson river valley. As the largest, most compact and most interesting territory, the Hudson river valley will best serve in illustrating the conditions and development of clay-industries.

The top of the Hudson river clay-deposits varies from 30 to 130 feet above mean tide-level. These deposits are stratified clays, lying nearly horizontal in terraces that have been eroded, leaving a steep, often precipitous, face extending to the river's edge. The regularity of these terraces, contrasted with the rocky crags and wooded crests by which they are surmounted, imparts the picturesque charm peculiar to Hudson river scenery.

In many places the advent of the brick-industry has converted the natural beauty of these shores into scenes of rude though active enterprise. The selection of a clay-deposit for industrial development required a level tract, either naturally or artificially formed, above mean tide-level, with a river-frontage along the base of the deposit. Upon this the plant was erected, the clay was mined, and manufacturing began. Aside from the introduction of steam-power, the use of better machinery, and the partial employment, here and there, of some modern improvement, the general method of manufacture to-day is practically as it began in the Hudson river valley. Thus while brick-making has elsewhere developed generally, it is here primitive and heterogeneous, with only occasional modern outfits. The absence of competitive territory has probably contributed largely to this condition.

The methods in vogue for mining clay are · 1. Digging with pick and shovel—unsystematically 2 Digging with pick and shovel—working by benches. 3. Excavating with plows and wheel-scrapers. The first method is not applicable to banks more than 20 feet high. The second method, working by benches from the bottom upwards, is the common one, the benches being made wide enough for a horse and cart. The last method is very little employed.

After the clay has been dug, it is usually conveyed in carts to the machines, an average haul of about 1000 feet. In many places the haul is now over half a mile. The road must be kept in repair, and frequently steep grades are unavoidable. At some localities the roads must be corduroyed in the wet season.

The production of 900,000,000 bricks will require 1,080,000 cubic yards of clay and 360,000 cubic yards of sand, which altogether will weigh 3,456,000 tons, to be handled in one season of 6 months. One horse and cart, with a haul of 1000 feet, can make 42 trips per 10 hours, conveying about 21 cubic yards (according to Trautwine, 14.3 cubic yards). On a basis of 150 working-days, the duty of one cart is 3150 cubic yards in a season. Therefore 457 horses and carts (minimum) must be employed in this work per season, and this number of horses must be fed and tended the year round. It is reasonable to suppose that the actual number engaged is greater than this. Each operator on a large scale would necessarily have a re-

serve; for, besides ordinary contingencies, mining and hauling clay under these circumstances are subject to weather conditions, and suspension for a day or two requires increased duty on resuming work, in order to make up the average output. Assuming the present average machine output to be 25,000 bricks per 10 hours, 3 horses and carts can supply one machine. According to all data obtainable, including those of personal experience, the substitution of cars drawn by horses on tracks effects only a slight diminution in cost. About the only advantage it offers is the possibility of continuous hauling irrespective of weather. The use of locomotives is cheaper for long hauls. Cars with a combination of power direct from the line-shaft and gravity-planes from the clay-bank furnish, undoubtedly, the best and most economical method of conveying clay to the machines.

The subject of mining clay economically and to the best advantage is still an open one. Operations in the summer season only, as now customary, suggest the use of the steam-shovel, by analogy with similar work in different fields. But the difference between the use of a steam-shovel as a mere excavating-machine and its use as a mining-machine should be borne in mind. Where it is available for the latter purpose, it will doubtless reduce the cost of mining below that of any other practicable method. It would be impossible, however, to use a steam-shovel located at the base of a clay-bank, the height of the bank and the tendency to "slides" preclude such an arrangement. Apparently the only way is to begin at the top, at a suitable elevation, corresponding to the sweep of the shovel, and carry out the bench horizontally, as begun, over the entire deposit, proceeding with successive levels in like manner to the bottom of the deposit. But this may involve serious disadvantages in working a deposit, the character of which has not been previously determined. In many of the developed localities the layers of clay differ from the top to the bottom of the deposit. This difference may not be confined to the chemical composition of the clay layers alone, but may extend to accidental materials lying between them. Accordingly, in working a deposit on a large scale, it might be advantageous to employ two shovels. For continuous operation through the year, the use of a steam-shovel requires suitable protection of

the clay-bank in winter, though in working day and night this would be unnecessary. For protection at night, mats made of straw or rushes, hung against the bank, will protect it, the crust of frozen clay being easily removed in the morning. It is perfectly feasible to work during the day only, in this manner, through severe winters. But the work should be planned so that mining will be uninterrupted. It is neither economical nor convenient to store wet clay, especially in winter.

In many instances the clay from the bank is shoveled direct into the brick-machines, otherwise, "tempering" in a ring-pit, by means of a single wheel, is still employed. The clay is shoveled from the pit into the machine. This method belongs to the wheelbarrow-era. In some cases the clay is fed direct into a pug-mill—a trough-like receptacle containing a revolving horizontal shaft armed with spirally arranged cutting-knives, by which the clay is broken up, mixed, tempered with water, and fed direct to the brick-machine.

The brick-machine commonly employed is a rectangular wooden receptacle, open at the top, and provided with a vertical shaft having horizontal arms. The lower arms or "wings" have a wide curved face, for forcing the clay into the press-box on the front of the machine. A vertical plunger in the press-box forces the clay through the "jack-mould," at the bottom of the press-box, into a wooden mould automatically presented to coincide therewith at each plunger-stroke. The previously moistened moulds are sanded before being pushed by an attendant into the space under the machine, each empty mould advancing to replace the preceding filled one. Hence the term "sand-moulded" bricks. The moulds are rectangular frames, open on top, having compartments for six bricks. As the filled moulds are pushed out sidewise in front of the machine, an attendant removes them. Another attendant receives and "dumps" the moulds on pallets,* upon which the bricks are usually dried. The pallets are successively presented by a fourth attendant.

With regard to drying, the best modern system only will be here described, since it applies equally well to all clay-products. Drying by artificial heat is accomplished by the use of steam,

* This name is given to the board or frame used for carrying newly moulded bricks

or hot air direct, with natural draught, or by either method with forced draught. The dryer, through which the heat is conducted, is a series of long tunnels, provided with doors at each end, built to accommodate a number of wheeled trucks or cars moving on tracks. For sand-moulded bricks the cars are constructed of angle-iron to form racks, having cleats or slides, capable of supporting 72 loaded pallets, or 432 bricks. When a complement of wood or steel pallets has been placed upon a car the latter is pushed along the track into the dryer. When the necessary amount of moisture has been expelled from the bricks the cars are drawn out in succession at the delivery-end of the dryer and conveyed to the kilns, where the bricks are removed from the pallets. By reason of the area covered by a single car with a rigid truck, all track-connections must be rectangular, and transference from one line of tracks to another must be accomplished by means of turntables, transfer-cars or cranes. A series of tunnels requires a series of corresponding tracks; hence, at each end of the dryer there must be facilities to change the direction of any line of track. Since these tracks traverse the entire plant, leading to the kilns and returning to the machines, a system of tracks interrupted by turntables, transfer-cars or cranes, is the unavoidable result. As a single car, weighing about 15 tons, contains 432 bricks, 60 cars are necessary for 25,000 bricks.

Since the drying takes more than 24 hours, a dryer for 25,000 bricks daily is supposed to contain 80 cars at one time. A nearly equal number of cars must be continually available outside, so that, for 25,000 bricks per day, about 150 cars with track-space, etc., are necessary. But the capacity of the modern machine is about 50,000 bricks per day, hence these figures must be practically doubled for each machine. And since a fair modern plant, with several machines, has an output of about 250,000 per day, it will be seen that track-room, dryer-space, cars, etc., assume enormous proportions. It will be easily seen that these cars, moved only by attendants over interrupted tracks, with an ever-increasing haul, leave the labor-problem still far from solution. But the difficulty does not relate to moving the cars only. To fulfill the conditions of a mechanical process, the progress of the clay from the time it leaves the bank to the time when it has been converted into finished bricks must be

subjected to the minimum of interruption. The customary method has been described above, to the point where the bricks in the mould have been placed upon a pallet. But further interruptions or re-handlings occur, which are most important, as follows. The pallets are placed on a car by two attendants; a third attendant moves away the loaded car; a fourth moves forward an empty car, from which he has previously removed the empty pallets. The loaded cars are now pushed into the dryer in the order in which they are to be drawn out at the other end. A fifth attendant draws the cars and pushes them to the kilns. The bricks are there removed by two attendants, who "toss" them to the "setter," a ninth attendant replacing the pallets as the cars are emptied. If two setters are employed, two or three additional men are required. These figures are given on the basis of a machine-capacity per day of 25,000 bricks only. As two men are needed to move the trains in the dryer, an extra attendant is required at night, the other being the night-fireman, who, as well the day-fireman, is not included in the above estimate. Omitting indispensable re-handlings, a critical analysis shows at this point from 8 to 10 interruptions, *i.e.*, the intervention of hand-labor by that number of men. After the kilns are filled and burned, the bricks must be removed from the kilns for shipment. This is commonly done by men with barrows. On an average, it will probably take 8 men to remove and load daily the quantity assumed as a basis of calculation. Four of these men would probably be indispensable under any system. The other four must be added to the above number, making a total of 14 men whose labor might be saved in a practical process, making 25,000 bricks per day. These figures are about the minimum of present practice, and hence conservative. It should be borne in mind, also, that a continuous mechanical process would also reduce the cost of manufacture in proportion to its increased speed and consequent daily capacity.

Before proceeding to a description of the system which I propose as a mechanical process, intended to obviate or reduce the defects above set forth, it may be well to revert briefly to the mining, conveying and preparing of clay, and to state the essential elements of the problem.

The first essential is that the clay shall be mined continu-

ously by a method, such as a steam-shovel system or its equivalent, that will insure an adequate regular supply. As the clay is mined it should be conveyed to each machine by means of automatic dump-cars on tracks. These tracks should be superposed at the machine in such manner that the clay will be delivered from the cars to a hopper. The hopper should be arranged to discharge into a "disintegrator"—a set of rolls provided with cutting-bars, or knives, for breaking up the clay uniformly. The disintegrator should be placed directly over the pug-mill into which it would feed, and the pug-mill, of course, should feed into the brick-machine. Thus the clay would pass from the bank, in a regular supply, properly prepared, directly into the brick-machine, without any interruption whatever. From the machine operating the "soft-mud" process here described, the clay would be formed into bricks, which would be received in the mould by the "mould-dumper." At this point it is proposed to supersede the methods in use by the roller-pallet system.

This system is intended to dispense with the turntable, the transfer-car, the crane, the separate car, and separate pallets, by mounting each pallet upon wheels, and combining the pallets, so mounted, in continuous belts, movable on tracks which extend singly or in series from the brick-making machine or machines to the various tunnels of a dryer, and thence to the kilns or any objective point about a plant; each pallet being moved on its tracks by means of ropes having stops or cleats which engage the pallets. A differential movement is imparted to the several ropes, so that, at various stages, the pallets may be moved either fast or slow, or only periodically advanced, as conditions may require. The several pallets are mounted in vertical series or columns, in separate tunnels of a dryer, and are gradually advanced through the latter, upon leaving which they travel in series in one vertical plane, if desirable, to the kilns, or any other objective point.

It is at the kilns that the bricks are handled for the first time after being placed upon the pallets. There they are removed from the pallets into the kilns and "set," and after being sufficiently burned are again piled upon the empty pallets, which latter travel over smooth tracks to the dock or station, carrying bricks ready for shipment. The pallets, after leaving the stationary

tracks adjacent to the brick-machines, are carried over any one of a series of shiftable track-sections, which are mechanically operated in such a manner that the several pallets will be supplied to the several tunnels of the dryer in vertical series, that is, after one of the series of tracks in a tunnel receives its supply of pallets, the track-section complementary thereto is shifted to a different altitude, so as to supply the pallets to another track. In this way the tunnels are filled from end to end, and from the bottom to the top, or *vice versâ*. Upon leaving the dryer, the pallets are conveyed over movable track-sections to a series of stationary tracks on different altitudes, but in vertical line with each other; and from the pallets on these tracks, which pass along the kilns, the bricks are taken and placed within the kilns. As thus arranged the system is an elevated one, with the advantages of free floor-space, and the chief advantage of conveying the dried bricks to the exact altitude where they are required. Each track in the vertical series has a slight downgrade from the stationary end, all the way around the kilns and back to the machines, where they are disposed in a horizontal series. It follows that the arrangement described is not arbitrary, any combination in vertical or horizontal series being available, limited only by the possibilities of track-arrangement.

It is apparent from this description that the roller-pallet system consists of an arrangement of tracks, either as a single circuit or a multiple circuit, over which pallets, mounted on rollers, are mechanically transported, one brick-machine, with a single circuit or track and a single tunnel, constituting the unit. On this principle, a plurality of brick-making machines with separate track-circuits can be operated so that each machine with its separate track-circuit is independent of the others. This likewise applies, as already mentioned, to the machinery supplying the clay, and is deemed a desirable feature in that department also. Power may be taken from an adjacent line-shaft, common to all the machines, or, if electric power is available, separate motors operating each machine and its independent system might be economical. It will, therefore, be clear that a perfectly simple plan may be comprised by a combination of five single-track circuits, each with a modern brick-machine and accessories, constituting a plant with a capacity of 250,000 bricks per 10 hours.

Light iron or steel rails are used for the tracks and supports. The pallets may be made of wood, iron or steel, preferably the latter. In this construction each pallet is composed of two thin plates, shaped like an ordinary pallet, between which are interposed longitudinal bars having their projecting ends rounded to form axles for the wheels or rollers, the latter preferably of malleable iron. The two plates and axle-bars of each pallet are secured together by bolts or rivets, and form a reversible roller-pallet, either side of which may be used. The ropes are ordinary wire ropes, having cleats or stops at regular intervals, corresponding to the width of the pallets. Power imparted to the ropes may be transmitted throughout the plant.

The roller-pallet system, thus applied, is calculated to secure advantages other than those already enumerated, and heretofore unattained. It is adapted to any plant-location, raw materials or process of manufacture. It is designed to lessen the number of handlings of both the green and the burned bricks, thereby insuring a better condition in the finished product. It will minimize the area of ground required for a brick-making plant. In illustration of this, it may be pointed out that a modern plant of the capacity indicated, but using cars, will require an area about five times greater than that occupied by the roller-pallet system. A further object of the roller-pallet system is to condense and centralize the arrangement of operating machinery and power to an extent heretofore impossible, resulting in a maximum economy, compactness and efficiency of plant.

The limits of this paper will not permit a more detailed account of this system, the description here presented being merely in the form of a brief announcement. For additional particulars, U S Patent No 644,520, 1900, may be consulted.

Further Notes on Elimination of Impurities from Copper in Refining and Converting.

BY EDWARD KELLER, BALTIMORE, MD

(Washington Meeting, February, 1900)

In a paper, "A Study of the Elimination of Impurities from Copper-Mattes, etc.," presented to the Institute at the Atlantic City meeting, February, 1898, I gave certain figures which I called the relative slaggability in refining copper. In that paper* will be found the following pertaining to this subject.

Relative Slaggability in Refining Converter-Copper.

Cu.	Pb	Bi	Sb	As	Se, Te
1	129.5	1.13	7.30	5.22	0.81

and

Relative Slaggability in Refining Electrolytic Copper.

Cu	Pb	Sb	As
1	41	9.97	7.13

Since there is a possibility of misinterpretation of the above values, the following supplementary information may seem justified in explanation. As the contents of impurities in the unrefined or crude copper were unknown, the contents of the refined copper were substituted therefor, merely in order to obtain the two series of figures for comparison. These figures are higher than they would be had I been able to take the correct ones for the unrefined copper. The high figure, 129.5, for lead, in the case of converter-copper, means simply that more lead was slagged from the crude copper than remained in the refined copper, or, in definite values, that to 1 per cent. of copper slagged, the ratio of the lead gone into the slag and the lead remaining in the refined copper is 129.5 : 100.

It is possible to approximate the true slaggability much more closely by adding the quantities of impurities in the refined copper to those in the slag, thus obtaining values for the crude copper in which the amounts volatilized are ignored (the latter

* *Trans.*, XXVIII, 140

being probably comparatively very small), and by calculating the amounts slagged as percentages of that sum. As a basis for such a calculation we have the following data.

Impurities in Refined Converter-Copper.

	Pb	Bi	Sb	As	Se, Te
Per cent ,	0 0103	0 0040	0 0630	0 0211	0 0072

Copper and Impurities in Slag.

	Cu	Pb	Bi	Sb	As	Se, Te
Per cent ,	44 47	0 5936	0 0020	0 2044	0 0490	0 0026
	Weight of Converter-Copper				Weight of Slag	
Pounds,	2,450,000				63,387	

Copper and Impurities in Slag, Expressed in Percentage of Copper-Charge

Cu	Pb	Bi	Sb	As	Se, Te
1 15	0 0154	0 00005	0 0053	0 0013	0 00007

Sum of Impurities in Slag and Refined Copper.

	Pb	Pi	Sb	As	Se, Te
Per cent.,	0 0257	0 00405	0 0683	0 0223	0 00727

From these we find the following results:

Relative Slaggability of Impurities in Copper-Refining.

	Cu	Pb	Bi	Sb	As	Se, Te
Per cent ,	. . 1	52 1	1 07	5 90	5 07	0 84

Although, as already observed, there is still an error in these figures, caused by ignoring the unknown amount of impurities volatilized in the refining process, they are undoubtedly a very fair approximation to the true ones. They are, in fact, more valuable as a metallurgical guide than values obtained by comparing directly the analytical results of crude and refined copper, for reasons that will be set forth hereafter.

Since the first publication of the above data I have had occasion to observe the refining of a quantity of black-copper, this being Chili bars. A sample of the bars had been obtained by probably the most approved method of commercial sampling of the present day. The furnace-charges of the refined product readily yielded correct samples. The same kind of copper had been worked in the furnace prior to the charge which was analyzed. Both black and refined copper were carefully ana-

lyzed with the subjoined results, from which the total elimination of impurities in the refining process is directly computed

Analysis of Chili Bars.

	Black-Copper Per cent	Refined Copper Per cent	Elimination of Impurities Per cent
Iron,	1 1378	0 0017	99 85
Cobalt,	0 1376	0 0044	96 80
Nickel,	0 1717	0 0975	43 23
Lead,	0 1105	0 0275	75 11
Bismuth,	0 2435	0 2285	6 12
Antimony,	0 0689	0 0673	2 32
Arsenic,	0 2055	0 2040	0 73
Selenium and Tellurium,	Trace	Trace	
Sulphur,	0 8100	0 0087	99 17

This copper, in comparison with former brands analyzed by myself, had the additional interest of containing appreciable amounts of iron, cobalt and nickel, on the other hand, it contained but a slight trace of selenium and tellurium. The small contents of silver and gold are omitted as being unnecessary in the discussion of the subject of this paper.

It will be observed that the quantities of antimony and arsenic eliminated from these Chili bars appear to be very small as compared to the quantities that were shown to slag off in the case of converter- and electrolytic copper, although the Chili copper has a much higher tenor of these elements, and should accordingly show a greater amount of loss. This will be more evident by direct comparison in the following manner.

Antimony and Arsenic in Slag, Expressed in Percentage of Converter-Copper Charge.

Sb	As
0.0053	0.0013

Antimony and Arsenic Eliminated from Chili Bars, Expressed in Percentage of Copper-Charge.

Sb	As
0.0016	0 0015

The indubitable discrepancy in the latter figures cannot be attributed to errors of analysis. They must be sought in the samples, and could undoubtedly be found in those from the bars. In the sampling of bar-copper (even in so-called approved

methods) by drilling, copper metallurgists still persist in committing the error of only drilling that portion of a bar, in shape a parallelopipedon, corresponding in dimensions to the height and bottom-surface of the bar, and ignoring entirely the beveled portion of the same. With many of the bars on the market, the proportion of the two, approximately, is the following: Parallelopipedon, 60 per cent; beveled portion, 40 per cent. Since, by reason of segregation, these two portions show a wide difference in composition, the sample generally is a deceptive one—sometimes in one direction, sometimes in the other—depending on the degree of purity of the copper.

With elements such as iron, cobalt, nickel and lead, which show a high figure of elimination, the error derived from sampling and other sources becomes, accordingly, less appreciable.

The possession of a number of corresponding samples of matte and converter-copper, kindly furnished by Dr James Douglas, from the Copper Queen mine, now enables me to add a few more members to the list of the companions of copper in mattes, with regard to their elimination in the converter.

Selenium and tellurium were individually determined in five blows of a converter, this number constituting the life of one lining. Nickel and cobalt were determined in all but the first blow.

I found the following results

In Matte.

No of blow	1	2	3	4	5	Average
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Copper,	50.95	51.95	55.58	60.00	59.90	
Selenium,	0.0094	0.0128	0.0092	0.0108	0.0145	
Tellurium,	0.0057	0.0092	0.0054	0.0064	0.0175	

In Copper.

Selenium,	0.0086	0.0107	0.0122	0.0121	0.0085
Tellurium,	0.0067	0.0087	0.0085	0.0084	0.0097

Elimination.

Selenium,	53.2	56.5	28.5	32.8	64.8	46.8
Tellurium,	40.2	50.9	12.4	29.9	66.7	40.0

In Matte.

Nickel,	0.0352	0.0298	0.0302	0.0412
Cobalt,	0.0296	0.0266	0.0156	0.0240

No of blow	<i>In Copper</i>					Average Per cent
	1 Per cent	2 Per cent	3 Per cent	4 Per cent	5 Per cent	
Nickel,		0 0356	0 0342	0 0374	0 0433	
Cobalt,		None	None	None	None	

<i>Elimination.</i>					
Nickel,	48 9	36 2	25 6	37 1	37 0
Cobalt,	Total	Total	Total	Total	

Regarding cobalt, I would remark, that although I failed to detect it in the copper, it is but reasonable to suppose that it is there present in traces; and, therefore, instead of accepting the elimination as complete, I would prefer to say that probably more than 99 per cent. of that element is eliminated.

Signal-Device for Mines.

BY C S HERZIG, VIRGINIA, MINN

(Canadian Meeting, August, 1900)

SOME time ago, in Mexico, our signal-bells in a 700-foot shaft caused us considerable annoyance by continually getting out of order, each time so delaying our hoisting operations that we naturally desired to remedy this evil. There were two ways open. either to patch up the old bell, which was of the ordinary pattern, every time it failed to work, or else to devise some new arrangement. On consultation with our foreman we designed a signal-device which, during the number of months I watched its operation, worked satisfactorily, without once getting out of order.

We sought to produce a simple device, in which no greater pull on the lever would be necessary from one level than from another, to counterbalance independently the weight of the pendant bell-rope, so that there would be no direct weight on the working-parts of the bell itself, and likewise to arrange it so as to necessitate only a light pull on the lever in signaling, and, finally, to make some sort of trip-arrangement, so that whenever the signaling-lever underground passed through a certain arc the signal would be given in the engine-room. By this means we wished to obviate the ill effects of sudden heavy pulls and rough usage in general, such as all signaling

systems encounter underground at the hands of careless or mischievous employees.

The bell-rope we had in use was a galvanized iron rope $\frac{7}{8}$ -inch in diameter; and, after determining the length needed, we calculated its weight, so that we might be able to counterbalance it properly. On locating the bell in the engine-room a wire, W , was led off horizontally, and, by means of a bell-crank, was connected to the main signal-rope, M , passing down the shaft (see Fig. 1). The weight w_2 counterbalances M , and should be heavy enough to carry the wires back to a normal position,

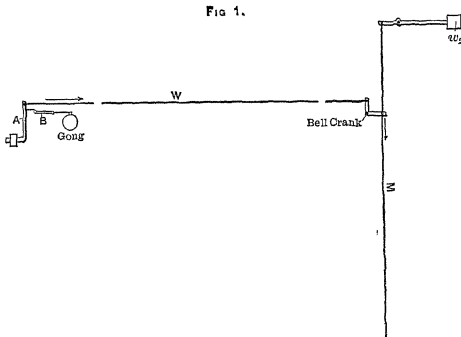


DIAGRAM SHOWING GENERAL ARRANGEMENT AND CONNECTIONS OF SIGNAL AND METHOD OF COUNTERBALANCING PENDANT ROPE

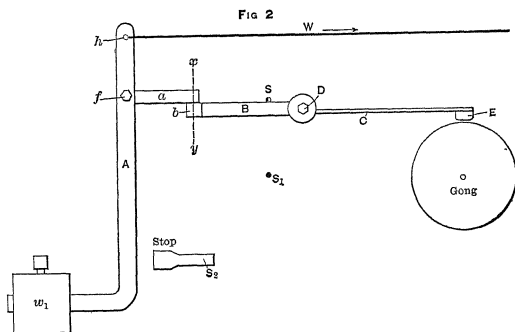
therefore it must be equivalent to the weight of the pendant rope, M , plus a factor to overcome friction.

The working parts of the bell itself are shown in Fig. 2. A is a weighted lever, to the upper end of which the connecting wire W is attached; the arm a projecting from it is made of steel, about 5 inches long, and has a bearing-surface of 1 inch at its further end, resting on a similar surface b on B . A cross-section through $x y$ is shown in Fig. 3.

B is a piece of flat spring-steel about 8 inches long, at the end of which is the bearing-surface b . D serves as a hub, to which B and C are attached; C being a flat spring similar to B , but about 12 to 14 inches long, at the end of which is the

knocker *E*. It should be observed that *B* is vertical, whereas *C* lies flat, and that *C* should not be as heavy a spring as *B*.

When the bell-rope is pulled to signal the engineer, the wire *W* moves in the direction of the arrow, and the arm *a* traveling downward in a circular path, around *f* as a center, forces *b* to move downward around *D* as a center, until the arcs in which they are traveling diverge far enough for gravity to carry *B-C* back again to its normal position, *B* being arrested by the stop *s*; however, the force with which the arm flies back causes the knocker to strike the gong, and thus give the signal. As soon as the bell-rope is released the arm *A* is carried back



SKETCH SHOWING DETAILS OF SIGNALLING DEVICE.
One tenth full size

to its original position, and in so doing the triangular surface on the end of *a* slides upon the inverted triangle *b* (see Fig. 4), forcing it to one side (see Fig. 5), until *a* rests in its normal position on top of *b*, when it is ready for another pull, as shown in Fig. 3.

In counterbalancing the weight of the pendant bell-rope, sufficient weight must be added to the counterbalance to bring the levers underground back into position automatically. The counterweight may be located at any convenient place on the head-frame, providing it is above the bell-crank to which *W* is attached.

In order to prevent the pull necessary for signaling from

becoming excessive, it is desirable to reduce friction as much as possible. A force equivalent to a 10-pound weight should be sufficient for pulling the levers in a well-arranged signaling-system. To accomplish this, I think it advisable to bring a bell-rope into proper alignment by means of plumb-lines, and to hold the rope in position by short pieces of old iron pipe 2 to 3 inches long, instead of by means of staples, as is so commonly done. In inclined shafts the bell-rope should be supported at frequent intervals on some form of roller. The spools on which connecting-wire comes make good rollers, in the absence of anything better.

That there may be no mistake, the arm *C* should be long enough, and the knocker *E* heavy enough to cause their instant return to position when the paths of *a* and *b* part company.

FIG 3.



SECTION THROUGH "Y" (FIG 2) *a* & *b* AT REST, READY FOR SIGNALLING
 $\frac{1}{2}$ full size.

FIG 4.



a & *b* ENGAGING AFTER SIGNAL HAS BEEN GIVEN.
 $\frac{1}{2}$ full size.

FIG 5.



A POSITION OF *a* & *b* SUCCEEDING THAT SHOWN IN FIG 4
 $\frac{1}{2}$ full size.

For this purpose it is also advisable to put a stop, *s*₁, below *B*, so that by no possible chance can it fly beyond its balance-point.

By increasing or diminishing the bearing of the triangles *a* and *b*, the arc traveled can be changed. In my opinion it is not advisable to increase this bearing above the inch mentioned before. The triangles, as shown in section, Fig. 3, should have bases of about $\frac{3}{4}$ inch, with perpendiculars of $\frac{3}{4}$ inch to 1 inch. The bearings of the two points *f* and *d* should be good ones, so that there will be no lateral motion, which might make *a* fail to engage properly with *b*. Any play at *d* or *f* is considerably magnified at the triangles; but by making the bases of these triangles large enough, the chances of their not working properly are greatly lessened. By moving the position of *h* with respect to the center *f*, the arc of pull underground, necessary to signal, can be regulated.

The spring B must be quite stiff and of good material, but it must be borne in mind that the stiffer the spring the heavier must be the weight w_1 and, in consequence, the greater the effort required to pull the levers; nevertheless, w_1 must be heavy enough to bring back the wire W and to overcome the resistance of the spring B . If the arm A is made sufficiently heavy, the use of a counterweight (w_1) may be dispensed with, although it is preferable to arrange as shown in Fig. 2, for by this means it can be properly adjusted. If w_1 is too heavy, the arm A has a tendency to pound against the stop s_1 . While w_1 must not be too heavy, its weight must not be cut down to such an extent as to impair the instant return to position of the arm A .

The whole apparatus may be mounted on a board and placed at some convenient spot in the engine-room.

Note on the Plate-Amalgamation of Gold and Silver.

BY E. A. H. TAYS, SAN JOSÉ DE GRACIA, SINALOA, MEXICO

(Washington Meeting, February, 1900)

As I promised, in a former paper on the Bryan Mill,* to give further data regarding the plates from four battery-aprons, I now submit the following:

These aprons were 4.5 feet wide by 16 feet long; the first two plates of each apron were 4.5 by 4.5 feet, and the remainder of varying sizes, as can be seen by their relative weights, as shown in the table; but all were 54 inches wide. They were in use 4 years and 9 months, and about 15,265 tons of ore passed over each. The ore was quartz, carrying about the same weight in silver as in gold, showing some copper, and highly impregnated with ferric oxide. The tailings show about 0.6 per cent, and the bullion about 10 per cent., of copper. The silver was present mostly as sulphide, and the copper was also present as sulphide, with some carbonate.

The ore treated in 1898 was a fair average of the whole run; so I take it as an example from which to make a few deductions.

* *Trans.*, xxix, 776

	Gold Oz	Silver Oz
The ore assayed, per ton,	0 76	0 71
The tailings, per ton,	0 22	0 44
Amount extracted, per ton,	0 54	0 27
Extraction, per cent,	71 1	39 4

From the above we see that the ratio by weight of gold to silver in the bullion produced, as per assays, should be 2 to 1

The average fineness of the bullion produced during the same period was gold, 658 80; silver, 240.80, showing a ratio of 2.74 to 1.

From the annexed table it will be seen that the several ratios on the aprons are .

Apron	Gold	Silver
1,	2 58	to 1
2,	2 65	to 1
3,	2 61	to 1
4,	2 58	to 1

One apron, No. 4, shows a regular gradual decline in value from top to bottom; all the rest show varying values, though the top plate is always richer than those below it, except in apron No. 2, where plate No. 4 is highest in value. Apron No. 1 is very irregular in the relative values of the successive plates.

All of these aprons would have given much more bullion, had not, in 1897, plates Nos. 1 and 2 of each apron been scraped very close with steel chisels. At least \$10,000 in gold was taken from each apron, but no special and exact record was made of the amount at the time.

In this case it is seen that, although the assays of the ore treated call for a ratio of 2 gold to 1 silver in the bullion, the actual ratio of the bullion produced was 2.74 to 1. The approximate average of the bullion recovered from the plates, when these were melted into bars, so as to make a fair average of the entire product, was 2.605 to 1; which shows but a slight variation from the bullion itself.

Over the Bryan-mill plates, already referred to, there passed about 24,440 tons of ore; and the bullion obtained from these showed a ratio of 2.31 gold to 1 silver, which is somewhat nearer the assay-ratio of 2 to 1.

From the above data we are led to infer that where all values contained in the plates are obtained together, all bullion, what-

ever its source, will have about the same ratio, and that the silver which is in fit form for amalgamation is just as amenable to it as the gold, showing no greater (or but little greater) tendency to resist amalgamation at the top than at the bottom of an apron. It is probable, however, that much depends, in this regard, on the nature of the ore treated.

Table Showing Values of Mill-Aprons Removed after a Run of Four Years and Nine Months.

Plate	Weight, Oz Troy	FINENESS IN		OUNCES OF FINE		Total Value	
		Gold	Silver	Gold	Silver		
Apron No I	1	1341 7715	92 00	38 70	123 443	51 927	\$2582 73
	2	1250 989	37 15	14 25	46 474	17 827	971 32
	3	1177 441	40 40	14 35	47 569	16 896	993 39
	4	662 9875	70 40	26 70	46 674	17 702	975 37
	5	1060 400	48 60	17 35	51 535	18 398	1076 27
	Ratio,	2 58 to	1				\$6599 08
Apron No II	1	1312 0245	52 90	22 00	69 406	28 865	\$1451 94
	2	1202 279	37 80	13 60	45 446	16 351	949 18
	3	756 1875	46 65	16 15	35 276	12 212	736 48
	4	785 075	63 40	22 70	49 774	17 821	1039.52
	5	771 600	47 30	17 95	36 497	13.850	762 70
	6	853 0375	48 80	19 05	41 628	16 250	870 20
Ratio,	2 65 to	1				\$5810 02	
Apron No III.	1	1210 9933	93 10	37 55	112.743	45.473	\$2337 68
	2	1719 0192	73 30	28 35	126 004	48 734	2633 74
	3	775 4875	75 30	27 45	58 394	21 287	1219 77
	4	619 125	34 05	10 50	21 081	6 500	439 64
	5	680 125	47 65	17 85	32 408	12 140	677 15
	6	825 200	47 50	19 90	39 197	16 421	820 05
Ratio,	2 61 to	1				\$8148 03	
Apron No IV	1	1155 000	78 20	34 10	90 321	39.386	\$1890 57
	2	1144 075	66 90	24 20	76 539	27 687	1598 67
	3	983 200	47 65	17 75	46 849	17 452	978 84
	4	1072 1625	36.75	13 75	39 402	14 742	823 20
	5	893 2375	34 30	12 10	30 637	10 808	639.75
	Ratio,	2 58 to	1				\$5931.12

A Device for Sampling Pig-Iron.

BY PORTER W SHIMER, EASTON, PA.

(Washington Meeting, February, 1900)

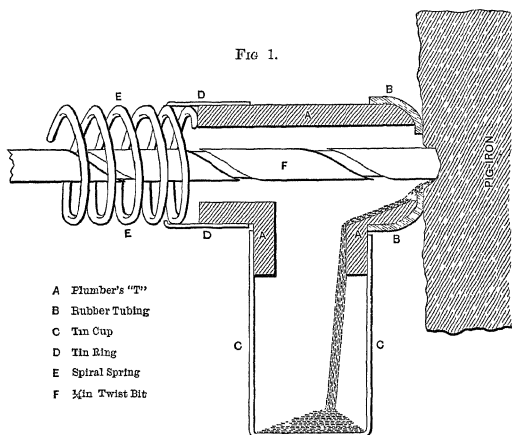
THE device here described has been found useful in sampling foundry-iron, and there is no reason why it should not be equally useful in sampling other metals, which are not too hard to be drilled with a breast-drill. It consists, as shown in Figs. 1 and 2, of an ordinary plumber's gas T (without bead) of about $\frac{1}{2}$ -inch in internal diameter, over the leg of which is snugly fitted a small tin cup, about $1\frac{3}{4}$ inches deep, to catch the drillings which are made by use of a breast-drill with a $\frac{1}{4}$ -inch twist bit, working through the arms of the T.

The forward arm of the T is filed down to a blunt edge, over which is stretched a short piece of rubber tubing projecting a little beyond the end. The bottom of the inside of the front arm of the T is filed down to a slope, to facilitate the passage of drillings into the tin cup. The rear arm of the T is fitted with a tin ring, projecting about $\frac{1}{4}$ -inch, for the purpose of holding in place a stiff spiral brass spring, which serves to press the sampler firmly against the metal to be drilled. The other end of the spring is supported against a shoulder of the breast-drill. The projecting rubber prevents the loss of any drillings, and also the falling of sand from above into the sampler. With ordinary care there need be no risk of getting particles of rubber into the sample.

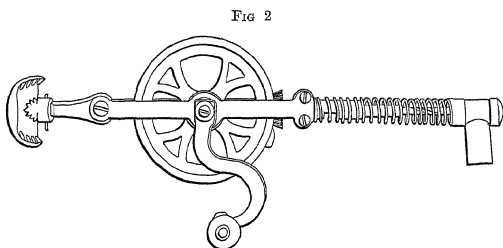
It is, of course, not possible to get a fair average sample of drillings, representing a pile of foundry-iron, by taking drillings from any one or two pieces, because of the frequently mixed character of the iron. This observation applies more particularly to the sampling of iron as it is broken and piled at the foundry, than to sampling at the works, where, if the furnace is working regularly, a few pigs may fairly represent a whole cast.

By the use of this device, it is possible for a sampler to pass

along a pile of pig-iron and take a little from each of ten or twenty or more pigs, by drilling a hole about $\frac{1}{8}$ -inch deep into each. A great advantage is that the drill-holes may be scattered



Longitudinal Section of Device for Sampling Pig-Iron Actual size.



Breast-Drill, with Device for Sampling Pig-Iron attached One-fourth actual size.

all over the fractures, making one hole in each piece, but in a different part of each. In this way, inaccurate sampling, whether due to an insufficient number of pigs drilled or to any

segregation in individual pieces, is readily avoided. It is necessary to brush off the fractures before drilling, to remove any adhering sand. It is also necessary to take as nearly as possible the same amount from each piece; otherwise the holes drilled into softer pieces will, very naturally, be deeper than those drilled into the harder pieces. When we remember that the softer pig-iron usually contains more silicon and less sulphur than the harder, the importance of this precaution is apparent.

Origin and Classification of Ore-Deposits.

BY CHARLES R. KEYES, DES MOINES, IOWA

(Washington Meeting, February, 1900)

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PREFATORY.

MUCH has been written on the genesis and classification of ore-deposits. Much remains yet to be written on the subject

before interest flags and a perfectly satisfactory scheme of arrangement appears. Each new contribution has had something of merit, something suggestive, something contributory in the way of presenting the subject from a slightly different view-point. At the same time each contribution has had something lacking, something not broad enough for later purposes, something in method insufficiently refined. Such is the status of every scientific inquiry, and such must it necessarily be at every stage of its advancement.

The usual so-called scientific considerations of the genesis of ore-bodies have always been, in large part, purely theoretical discussions. Comparatively little attention has been paid to the real bearings of the theme. As time has gone on, there have come into existence several groups of theorists, of which the rival schools of the Ascensionists and the Lateral-Secretionists are now the most prominent.

On the other hand, the average miner of ores, in whatever consideration he has been able to give to the subject of ores and their classification, has avoided the problem of origin altogether. He has practically ignored all those aspects of the ores which are so engrossing to the scientist.

In reality, the knowledge of both classes of workers must be drawn upon to the fullest extent, before the best results can be hoped for in attaining a satisfactory systematic scheme of ore-deposits.

A careful survey of the real nature of ore-bodies, when it comes to their classification, indicates that, at the outset, every such plan should be useful. As it is built up, it must, among many other features, consider that of aiding exploitation. All conditions are believed to be best satisfied by always keeping prominently in the foreground the factors which govern the geological occurrence of the ore-bodies themselves, and the geological relationships of the country-rock. Hence, in venturing, at this time, some observations upon the classification of ore-deposits, it is chiefly from the geological view-point that the subject is approached.

Such a plan is essentially an arrangement of the geological processes, so far as they affect specifically the ore-bodies and their original deposition. The resulting ore-classification itself is in terms of the forms of ore-bodies as geological formations

or terranes, and as dependent upon geological structure. This basis appears to be the only one that is truly genetic in nature.

The data for an ore-classification of this kind are derived largely from the great advancement recently made in the study of the crystalline schists and metamorphic rocks in general, as the result of the application of the microscope. As, to the mineralogist, the lithologist and the geologist, a field illimitable has opened out, so, through the same means, the student of ore-genesis now finds before him a field equally vast. It is full of promise. Answers to many problems long unsolved seem already within our grasp.

It should be borne in mind that only the barest outline or synopsis of the general scheme can be here presented. The plan, however, is capable of great expansion and wide illustration. This part of the theme is more fully developed in another place. The present consideration of ore-deposits has, therefore, to do with their classification rather than their origin, though to the nature of the latter the former is closely and directly related.

FOUNDATION OF CLASSIFICATORY SCHEMES IN GENERAL.

It has been recently said with much truth that, at the time it is constructed, every plan of classification reflects directly the existing stage of knowledge in its particular branch. As classification is really history in epitome, one of the first considerations to receive attention is a systematization of the known facts. This orderly arrangement is one of the earliest prerequisites demanded of a science claiming recognition; and all advance is measured by the degree of taxonomic completeness shown, and the kind of criteria adopted. The bringing together of the various facts observed so that some sort of classificatory relationship is made to exist among them, is the initial step in raising a particular department of knowledge toward the dignity of a science. As progress is made, a gradual evolution takes place in the fundamental manner of grouping the phenomena.

In the beginning, a classification, rude though it be, is fashioned according to those superficial features which, at first glance, are most striking. At a later stage, this is modified to one in which similarity of characters, irrespective of natural relations, is taken into account. A vastly more advanced conception is

classification based upon affinity, in which, for similarity of features, there is substituted similarity of plan. The final stage is the causal, in which origin and the agencies become dominant and determining factors.

Our knowledge of ore-deposits has now advanced far enough for them to be considered according to the methods of this final stage, in connection with the grander geological agencies and physical conditions that have given to them the various forms in which we find them.

In considering the classification of ore-deposits, we meet on the one hand the crude distinctions of the miner, based upon the fortuitous forms which ore-bodies assume; and, on the other hand, the refined, but often impracticable, schemes of the *doctrinaire*.

The great thing sought for in the classification of ore-bodies is a system that is genetic as far as possible, that is practical in application, and that will aid in their discovery and development. Such a scheme should be made so that the most ordinary miner may use it. At the same time it should not offend the most rigid theorist. This common ground seems to be found by giving due consideration to certain geological principles that have recently been found to have a special bearing upon the deposition of ores.

PAST OPINION REGARDING CLASSIFICATION OF ORE-BODIES.

The earlier schemes of ore-classification followed chiefly the empirical methods of the miner, and made the shape of the ore-body the most important factor. Von Oppel, Werner, Von Weissenbach, Von Cotta, Koehler, Callon and others, all make form the distinguishing feature in the grouping of ore-deposits.

Later, the method of concentration of the ore-particles became a dominant standard. The schemes of Whitney, Newberry, Phillips, Grimm, Von Groddeck and Pumpelly may be mentioned as prominently emphasizing this feature.

Of late, various attempts at strictly genetic plans have been made. Prominent among these schemes are those of Wadsworth, Munroe, Kemp, Pošepný, Power, Crosby and Fuchs and De Launay.

NATURE OF ORE-DEPOSITS.

Definition.—Ore-deposits are generally defined as localized accumulations of metalliferous compounds. As thus under-

stood, it is quite patent that the term is necessarily a loose, popular one, applied wholly without reference to the real genctic relationships of the ore-bodies. With the name, however, is always carried the idea of concentration sufficiently great for profitable mining.

In this light, ore-deposits form a natural class of mineral formations that are clearly set off from all others by their nature, and largely also by the methods followed in their development. Hence they are entitled to a special classification wholly independent of other economic deposits, and of the geological formations in which they occur. The other economic deposits are to all intents and purposes geological formations, and may be so considered, without any elaborate attempt at special systematic arrangement.

Fundamental Law of Origin.—Concentration appears to be a primal result of the moving of rock-materials. It makes small difference whether the general movements of the rock-particles take place chemically through solution, mechanically through the agency of waters, or in a liquid magma, the results are largely the same. Rock-forming materials of like mineralogical constitution tend to gather together, before they come finally to rest. Geological formations or terranes are in reality nothing but concentrates of similar rock-material, only less complete and less noticeable than in the special case of ore-bodies.

Significance of Ore-Bodies.—From a strictly scientific standpoint, the specific shape and character of ore-bodies is often apparently fortuitous. The minute metallic particles composing them are, in one form or another, everywhere widely disseminated through the rocks that make up the earth's crust. Whenever an area is disturbed by mountain-making forces, unstable conditions are at once established; new currents of underground waters are set in motion; molten rock-masses may be introduced; and all the rocks of the region sooner or later begin to undergo alteration. Along with the rock-changes at this time, ore-particles are transported and localized. Hence, ore-bodies are special phases of the most common of geological phenomena.

Owing to the peculiar rôle that they play in our civilization, most ores are popularly supposed to result from some special dispensation of nature. Their existence in quantities large enough to be of commercial value depends wholly upon a com-

bination of many circumstances, the absence of any one of which might cause the process of concentration to fail

Date of Origin.—For the most part, ores and their commonly associated minerals may be regarded, in a broad way, as space-fillers in the country-rock. In common with certain non-metalliferous substances, their chief geological function is often to cement or render compact rock-masses that have become porous or cavernous through partial solution, cracking, or the irregular slipping of parts, usually during the periods of disturbance in mountain-building. The dates of these disturbances are thus important factors in attempting to fix the time of local ore-deposition.

Usually the age of a rock-mass is thought to be determined, in a general way, by the fossils contained. The ores enclosed in such a terrane have long been regarded as having been formed at about the same time as the rock. This, however, is now known to be rarely the case. As a rule, ore-formation takes place long after the formation of the country-rock. Often there are several periods of ore-formation in the same rock-terrane. Ore-deposition may be of very late date in rocks very old.

The majority of the more common mineral veins, especially those occurring in clastic rocks, are doubtless of comparatively late origin. It is also quite probable that most of the worked ore-deposits of the world have been entirely formed in very recent geological times. Few, perhaps, date back before the Tertiary. While some ore-deposits are manifestly ancient, some of the most important opened may have been formed within the memory of man. This phase of the origin of ore-deposits is one as yet but little considered.

It is also important, in this connection, to remember that in all recently disturbed regions ordinary ore-formation is in all likelihood going on to-day as rapidly as it has usually gone on in the past, or may be expected ever to go on hereafter.

Original Source of Ores—From the standpoint of mining, it is of small consequence what was the condition of the ores previous to their concentration into bodies of economic value. Whether the original source was the unoxidized metals, coming up from the earth's interior in connection with molten rock-materials, hot water and gases, or whether there was deposition from lateral secretion, need not concern us here.

While most igneous rocks, as shown by Sandberger, contain appreciable amounts of many metals which, on weathering, may be set free and allowed to be transported and concentrated, it by no means follows that the small quantities of metalliferous substances found in the clastics are due to direct incorporation during the deposition of the sedimentary beds. Finely porous rocks are likely to have metallic ores deposited in their interstices from circulating waters, in the same way as those rocks which have larger cavities.

Alteration of Ore-Bodies —In the consideration of ore-bodies, distinction is to be clearly made between the original character of the ores as geological formations, and the constitution which they subsequently assumed. Geologically, as well as from the standpoint of rational ore-classification, the deposition of the ore-body as a rock-formation is all-important; the subsequent changes that ores undergo after once being deposited are of secondary consequence. The original mineralogical condition is not always easily to be made out, but the instances are rare in which it is not more or less clearly indicated in some way.

Ore-bodies once formed have, like rocks when brought towards the surface through uncovering by erosion, a tendency to form carbon or oxygen compounds; and, when buried by sediments and shut off from the air, to silicify, or form silica compounds. Whatever may have been their original composition, all ores are liable to constant alteration. These changes are often so numerous and so complicated that it is well-nigh impossible to determine the real genesis of the ore-bodies without fully taking account of their geological relationships.

The profound alterations that ores undergo, and the intricate character of most of these changes, are only indicative of the constant mutations that take place in rocks generally. But, owing to the economic value of ores, the specific characters which they assume have a widespread interest; while, in the case of the rocks, analogous changes are appreciated only by a few adept workers in petrography.

All these factors are of vast importance in every consideration of ore-deposits. They throw a wholly new light upon many problems constantly coming up, and indicate how necessary it is to take into account the factor of geological environment.

GENERAL METHODS OF ORE-FORMATION.

Ascension versus Lateral Secretion — The two principal theories of ore-deposition have pretty evenly divided those interested in the subject into two somewhat hostile camps. In fact, the question stands on a very different basis from that suggested by either of the two theories in question. As will be seen further on, it is really of small practical importance whether ore-materials are deposited from hot mineral-bearing waters welling up from the depths of the earth, or from the cooler waters which have gathered up metals in their travels through the rocks near the surface, and which are then forced to drop the loads they have held in solution for a greater or less length of time.

The mode of ore-formation from circulating underground waters is a general method. It cannot well be disputed that the cooling of the waters, however slight, is an important factor in compelling them to deposit what they contain in solution. Whether the waters are hot, warm, or cool, matters not. Of course, hot waters coming to the surface of the earth will part with their soluble contents more rapidly than those having much lower temperatures. The difference is merely one of degree, and not of kind. The same is true of most of the other general processes involved in the production of ores.

There can be no doubt that a majority of the great ore-bodies of the globe are formed from metalliferous heated waters ascending to the surface. It is equally beyond all doubt that many very important ore-bodies have been deposited by waters that were never hot, that were never associated with volcanic action, and that have circulated only near or on the surface. In some cases one method has been followed, in others another. We cannot say that all ores have been formed either in one way or the other.

The determination of local ore-deposition is thus probably more largely a function of the capacity of the country-rock along the courses of the water-currents, to be replaced, particle by particle, by metallic minerals. In either case the chemistry is essentially the same. It is, however, a general process, and in classification it is a factor that may be neglected altogether.

Replacement — In the formation of ore-bodies, the opinion has been quite general, until lately, that, in the main, they merely filled pre-existing cavities and caverns in country-rocks. Of

late, many writers on ore-deposits have been inclined to put more or less stress on what they are pleased to call the replacement theory, as revolutionizing our ideas regarding the deposition of ores. The central feature of the replacement hypothesis, namely, that, in many cases at least, no previous cavity existed, but that circulating waters, percolating through the rocks, dissolved certain zones or tracts which are replaced, molecule by molecule, with ore-materials and their accompanying gangues, greatly simplifies matters in a large number of cases, and greatly aids in the interpretation of many others.

To the petrographer, who is accustomed to apply the microscope to the rocks, this general process of replacement is widely known as metasomatism. It is one of the most universal methods by which changes take place among the rocks. Alterations of this kind go on actively in all rocks subjected to deformation, even in such masses as granite, which is about as non-porous as rock can be.

It may be further observed, in this connection, that metasomatic changes in the rocks are far from being unusual, they take place with very nearly the same ease as do the metabolic changes in living organisms. All modifications in the physical surroundings of rock-masses find immediate response in chemical reactions in the rock-masses themselves.

Not only may replacement, molecule by molecule, take place between the constituents of a rock and mineral particles brought in by percolating waters, but reactions may be set up between contiguous constituents that are essential parts of the rock itself, forming wholly new minerals, often capable of segregating into considerable masses by themselves. Furthermore, external physical changes, such as are produced by deformation, for instance, permit one molecule in a given mineral constituent to separate into two or several, without any marked replacement from outside sources.

Nor is this all. In petrography many other distinct phases than those mentioned are already recognized, in which metasomatism is actively engaged; and more are being constantly found. The refinements in this particular are already such as no consideration of ore-deposits can ever be expected to attain. So far as ores are concerned, only the grand general proposition can be utilized.

General Factors in Classification.—The ascension, from the depths, of heated waters containing ore-materials, the transfer of metallic substances from the rocks near the surface to the cracks and crevices in them, and the replacement of a rock-molecule by an ore-molecule, are all general methods of ore-segregation. Their operation involves chemical changes that we cannot always determine or even well understand, much less practically use in the exploitation of the ore-bodies. The same is true of all other general processes involved in ore-formation. It is self-evident that such general factors give rise to few features which enable the ore-bodies to be advantageously classified.

Genesis in Ore-Classification.—When, in the classification of ore-deposits, primary importance is given to these agencies, we would expect to have the nearest approach to the highest type of systematic schemes—the genetic. However, most of the latest attempts to classify ores according to origin are fatally faulty, in that there is almost complete failure to recognize the essence of the genetic principle. “Genetic plan” is an attractive title. It is widely used in other departments of science, but, as usually applied to ores, the plans thus far proposed are genetic in name only. A truly genetic arrangement of ore-deposits must first of all take into account the metallic accumulations as ore-bodies. Then their relationships to the physical agencies or processes forming them should be pointed out.

To refer ore-deposits directly to the causes producing them, instantly does away with the very principle lying at the base of all classification. From this practical standpoint, ores of all descriptions are jumbled together. Instead of orderly, helpful arrangement, there is chaos worse confounded. For instance, a classification of ores having the chemical mode of deposition as the principal criterion, meets with the very same difficulties as attend a chemical classification of rocks. To be sure, it is possible to form such a scheme for rock-masses, but in practical geological work it is perfectly useless. Classification of ore-bodies, in which chemical formation is the primary standard, equally falls short of meeting the requirements of the problem.

A purely genetic classification of ore-deposits is, therefore, neither practicable nor desirable. The very definition of the

word ore makes it inadvisable even to attempt to construct a practical scheme that is, in its nature, strictly genetic. While some such systematic plan may be in a general way framed for rock-masses, and while ores may be regarded as rock-bodies, the unscientific character of the group of substances going under the name of ores, makes a similar scheme for ore-deposits almost worthless.

The fact that an ore is any metallic substance that accidentally accumulates locally in sufficient quantity to be utilized by man, precludes, in practice, the establishment of any close relationships between the different deposits, based wholly upon genesis. A parallel case is found in botany. A classification of useful fruits would give small indication of their morphological and genetic relationships.

The physical and chemical agencies immediately involved in the formation of ore-deposits must therefore be conceded to be of minor importance in classification. Metasomasis, already alluded to, which in "genetic" schemes gives rise to a primary group of ore-deposits, is a general process, and should find no place in any classification. The same is true of many other chemical modes of activity. All these are of vast importance in the consideration of ores, but surely not as criteria of classification.

LITERATURE OF ORE-DEPOSITS.

Although it cannot be said of some of the more recent descriptions, it is nevertheless very remarkable that so voluminous a literature as that which treats of ore-deposits contains comparatively so little that can be worked over, as it were, for purposes other than mere record. One of the chief functions of a scientific literature is to enable workers to take some things on authority, and be relieved of doing everything over again from the beginning. Yet how little of the work of others is really available is amply shown by reference to any of our treatises or text-books on ores. It seems impossible to get much that is satisfactory concerning the exact manner of occurrence, the data affecting origin, and clearly stated information as to the relationships of the ore-bodies to the country-rock. Of late not a few writers have called attention to these points; and none more forcibly than Pošepný.

Nor have these appeals been in vain. Along the lines men-

tioned great changes are evinced by the most recent ore-literature. For full confirmation of this statement one has only to refer to the last volumes of the Transactions of our Institute, or the monographs and papers of the U. S. Geological Survey.

Much less are we able to gather from the literature of this subject material adequate in amount and character to be used in a scheme of classification, for example. We seldom realize how faulty the data are until we attempt to arrange the subject-matter systematically. This is the acknowledged experience of every text-book maker. In this regard there appears to be no branch of science worse off than mining.

Taking classification as an illustration, it makes little difference what standard is considered in connection with ore-bodies, the shortcomings of ore-literature, as a source of suitable and satisfactory illustrations, are on every hand painfully manifest. Even when our text-books on ore-deposits are tested by their own criteria, the illustrations cited and described as typical examples of particular classes include so many wrongly-inferred cases that it almost becomes necessary to verify personally every citation before it can be utilized with confidence.

That so large a part of the published information concerning ore-deposits is unscientific in its character, is due to certain peculiar conditions not met with in other branches of knowledge. When I say unscientific I mean in the sense of lacking exact discrimination in both observation and statement. It is not, on the whole, the high-grade work that the geologist is accustomed to perform in his every-day efforts, or that the mining engineer does in his plans drawn with mathematical precision. For this seeming carelessness neither the geologist nor the engineer is wholly to be blamed, notwithstanding the fact that the failure is due to both.

At the time when ores are usually examined with reference to their main features as ore-bodies, their genetic and specific characters are secondary considerations; other things demanding more time and attention. In the one case, the scientist is busy with the geology of the region; and the ores can at the same time receive only incidental study. The time for their special investigation rarely arrives, so far as he is concerned. On the other hand, the engineer, while endeavoring to develop the ores, has his time taken up largely with the mechanical

difficulties of mining operations. Before he is able to go back for thorough and exact scientific investigation, he too is called to other fields.

Thus, while many of the latest publications on ore-deposits are all that could be desired, a large part of ore-literature is unavailable as a basis for scientific statements regarding ore-classification, unless one is personally acquainted somewhat with the localities themselves. As to the great majority of developed ore-bodies already described, further inquiry is necessary before they can be judged by any of the standards yet proposed. In the present paper, selection has been made, in each category, of one or two illustrations, that are well-known occurrences. At the same time, specific reference is made to the best published descriptions, in order that the details may be readily examined in connection with the observations here offered.

CRITERIA OF ORE-CLASSIFICATION.

As all classification must be regarded as more or less practical in its bearings, so one of ores should be of such a character that, as its most conspicuous feature, it can be made useful in their development. With this end constantly in mind, the formation of a systematic scheme of ore-deposits loses many of the difficulties usually encountered.

All attempts to arrange ore-deposits systematically have proved unsatisfactory, partly because no strictly scientific scheme of classification is possible, and partly because the practical mining phases of the question and the fundamental geological principles have never been properly co-ordinated. In such an adjustment seems to lie the most hopeful outlook.

The usual principles followed in ore-classification have given diverse results, according as special stress has been placed on this or that feature. From the standpoint of mining, for example, mineral content is of first importance; in the most scientific plan possible, it is last. Again, to the miner, ore-origin is of least interest, from the theoretical scientist it receives attention before all else.

While the principal factors that have been relied upon as criteria in the classification of ore-deposits are not many, they have been used so differently and with such varied emphasis that the subject has become much more complex than might

be expected. It is neither necessary nor desirable at this time to make a complete review of these criteria and the varied senses in which the terms have been employed. Some of the most conspicuous standards, however, may be mentioned. These are. ore-content; form of ore-body; mode of chemical formation; mode of physical formation, lithological character of filling, texture; position with reference to structure of country-rock, and origin with reference to the country-rock.

Thus, it is naturally inferred that ore-deposits present so many aspects for consideration that, in order to make a classification of them lasting and practical, it must be made as acceptable as possible to all concerned. How this can best be done becomes a two-fold problem. We get a hint towards its solution from the astute statement of Crosby, that "It is generally conceded that, whatever the limits of classification, its highest value, both as a means of education and as an aid in the discovery and exploitation of deposits, demands that it should be essentially geological, and not be based, at least in its main lines, upon the qualities or uses of the materials."

This observation is no doubt due largely to a realization of the recent tremendous influence which geology has exerted upon mining and its methods. This influence gives geological occurrence first place in the consideration of ore-bodies. In attempting to arrange a comprehensive and practical scheme of classification for ore-deposits, it is thus quite manifest that the relationships which the deposits bear to the geological formations in which they occur come to be critical criteria. So, too, the physical agencies operating upon the geological formations must have the utmost consideration. These factors may not always be clearly emphasized in a direct way, but they should be everywhere implied. The manner of deposition of an ore as a geological formation not only becomes an important practical feature, but in classification a prime factor.

For the most part, ore-bodies are geologically secondary formations. With some exceptions, they have accumulated long after the country-rock has been formed. While it has been widely recognized that close relationships exist between the formation of most ore-bodies and the character of their matrix, the vastly broader generalizations regarding the intimate association of ores with geological structures have not received so much attention.

As a usual thing, the exploitation of ore-bodies has been carried on in accordance with rules which the very limited experience of the individual has pointed out. Where an operator, untrained in scientific earth-lore, begins mining in an undeveloped district, his method of attacking the various problems presented is most likely to be after that of his nearest observations elsewhere. He may hit upon the right plan of work at once; but the chances are ten to one that he will not. Only after repeated trials and many failures, and after much fruitless expenditure of time and energy, does he finally reach satisfactory results.

When, however, a specially trained geologist undertakes to make an investigation of a mining property, he, first of all, gets his bearings, as it were, with regard to the geological structure of the region and the distribution of the rock-formations. At once he eliminates nine-tenths of the chances of failure in arriving at the best plan for operation. Instead of a great game of chance, the development becomes a strictly business proposition.

These two methods of procedure indicate the essential differences between the old and new ways of carrying on mining operations. In fine, the intelligent exploitation of ore-deposits must have a broad geological basis.

The nearest approach to a truly genetic classification of ore-deposits is one which presents as prominently as possible the underlying principle of cause and effect. All products should find accurate expression in terms of the geological agencies. Only then are the broader distinctions in classification made possible. The various taxonomic groups are clearly separable only when it is recognized how and in what manner the components of the materials dealt with are influenced. Under one set of agencies and conditions, ore-materials are affected in one way. Under another set of conditions they act altogether differently. It is inferred, therefore, that the primary groupings of ore-bodies find their best expression when based upon the manner in which the agencies affect them, and the implied nature of these agencies.

This is perhaps more clearly expressed by the accompanying scheme, in which the groups and categories of ore-deposition are tabulated, and paralleled with some of the general forms of ore-bodies commonly recognized by miners.

Classification of Ore-Deposits.

Groups	Categories	Miners' Forms
I HYPOTAXIC Mainly surface deposits	Aqueous transportation Residual cumulation Precipitative action.	Placers Pockets (in part) Bog-bodies, some beds, layers.
II EUTAXIC Chiefly stratified formations	Original sedimentation Selective dissemination Emponded amassment Fold-filling Cievice accretion Concretionary accumulation Metamorphic replacement.	Beds, strata, layers Impregnations (in part) Masses (in part), some segregations Saddle-reefs Gash-veins, stock-works (in part) Nodules Fahlbands (in part), beds.
III ATAXIC Predominantly unstratified and irregular bodies	Magmatic secretion Metamorphic segregation Fumeiole impregnation Piferential collection Fissure-occupation	Masses (in part), some lenses Stocks, lenses Contact-veins, some impregnations Chambers (in part), some pockets, linked-veins Attition-veins (in part), some linked-veins, true veins.

PRIMARY GROUPING OF ORE-DEPOSITS.

Viewed broadly from geological and practical standpoints, the consideration of the major divisions of ore-deposits somewhat after the plan of Whitney, as afterwards adopted by Newberry, Phillips and others, seems to harmonize more nearly than any other distinction yet drawn, with the most modern conceptions regarding the real nature and relations of metaliferous bodies. In the scheme suggested above, ore-bodies are regarded as (1) surface-deposits, (2) stratified deposits, or (3) unstratified deposits. Under the new interpretations of the manner of most ore-depositions and dependence of their character largely upon the conditions imposed by the local rock-surroundings, this triple subdivision can be, it is believed, readily adapted to the more advanced conceptions. Although by no means the same, or based strictly upon the same ground, or even bearing the same terminology, as that of Whitney, it still seems to be mere justice to credit him with originating the main idea.

This primary grouping, as now understood, is not only scientific, so far as it is possible to make a classification of economic deposits scientific, taking into full account the genetic processes, but it is also the most natural one, and the one of which the greatest use can be made in exploitation.

While in every classification there must always be individual cases which do not appear to belong to any group, or which may be put in one place as well as another, the lines between the three great groups here recognized are certainly as sharp as between any yet proposed, and as marked as one can ever reasonably expect such lines to be drawn. The distinctions are usually readily made in the field, without the necessity of going through any elaborate and refined investigation. The determination of the great group to which a particular ore-body should belong requires no special theoretical consideration and no discussion of mooted points. The most advantageous method of investigation is at once suggested. For each group of deposits demands a course of procedure very different from that of the others.

The chief merit of this primary subdivision is that it now recognizes to its fullest extent the grander groups of geological agencies, which we are accustomed to call the hypogene and epigene processes. The surface or superficial ores constitute a small group by themselves, the result of a special phase of the first-named group, and hence are best considered independently of the other two. The ores incorporated under the term Eutaxic, meaning well arranged as ore-bodies, are "stratified" only in the sense that they are associated almost exclusively with the stratified rocks, and their mode of occurrence is dependent upon the geological structure of these terranes. In the same way the Ataxic ores prevail largely among the "unstratified," or massive, formations, or, when in the clastics, are wholly independent of the laws governing the stratified structures.

While the names used by Whitney are not all we could desire in the interest of exact nomenclature, it still seems that, with some modification of the original ideas held by that author, they can be used as alternate terms to meet present requirements. It appears advantageous and necessary in all cases of this kind, when the conceptions are fundamentally different, to retain something of the old terminology, especially when it is

widely known. While the followers of Whitney may not be able to recognize fully the change of meaning or the new applications and extensions of his terms, the utilization of old names gives to all, who have been accustomed to them, something of the general idea of the new. None except the ultra-specialist need find fault with such a method.

Still, there are many who would prefer to have the new conceptions called by new names. In the present instance, bearing in mind in a very general way the same idea as before, the three groups are referred to as Hypotaxic, Eutaxic and Ataxic, meaning, *somewhat* arranged, *well* arranged, and *not* arranged, with reference to their general geological structure and the geological structure of the associated rocks.

Now, in making the foregoing suggestions in regard to the lines along which, it is thought, should be built a classification of such heterogenous bodies as the ore-deposits, it is fully recognized that any attempt to adhere, as far as possible, to well-known terms and plans is fraught with danger of being wholly misunderstood. The wisdom, or lack of it, may be seen later. However, this possible contingency is partly met by rather fuller explanations of the taxonomic groups than might otherwise be considered necessary.

In regard to these major groups, the use of Whitney's names as alternate terms might appear to invite, for the plan here outlined, all the accumulated criticism offered to the schemes of Whitney, Phillips, Von Groddeck and Pumpelly, that the subdivisions are unscientific, confuse criteria, violate the primary canons of classification, and are not genetic in nature. As used in the present connection, the titles "surface," "stratified" and "unstratified" are merely descriptive names, neither equivalents of the new terms, nor genetic terms.

The principal titles here used indicate the most obvious structures and geological relations of the ore-bodies, regarded as geological formations, or terranes, if they might be so called. The treatment is from the viewpoint of the modern study of rock-metamorphism. If one were permitted to generalize, without calling attention in detail to numerous exceptions that are more apparent than real, and are due to local modifications of conditions, the relationships of these principal groups might be tabulated as shown in the following table:

Relations	Hypotaxic	Eutaxic	Ataxic
Dynamic.	Epigene	Epigene	Hypogene
Genetic	Suspension	Solution	Mineralization
Depositive.	Sedimentary	Sedimentary.	Igneous
Locative	Superficial zone	Weathered zone	Cementation zone
Formal	Pockets	Beds	Veins
Structural.	Substratified	Stratified	Unstratified
Chemical	Oxidation	Carbonation	Silicification

Hypotaxic (Surface) Deposits — While this group of ore-accumulations might be included with the Eutaxic, or “stratified” group, its members present so many peculiarities in mode of origin and geological occurrence that they are advantageously considered by themselves

The formation of ore-bodies on the surface of the earth conforms to the ordinary chemical and physical reactions, as these are inferred from their manifestations among the much larger class of rock-materials, of which the ores constitute but a very small fraction. On the surface of the globe, transportation and concentration through the most familiar geological agencies, and chemical reactions, take place as we are most accustomed to observe them. The workings of the common laws of chemistry and physics are not obscured and modified by the absence of air, and the introduction of the factors of high temperatures and great pressures

The strictly mechanically-formed bodies are peculiar to this group. The reason why the deposits of this kind are not more important as a whole is that the very processes which produce them usually do not stop their workings as soon as considerable ore-bodies are formed, but continue their activities, and soon remove the ores again, along with the associated country-rock.

Eutaxic (Stratified) Deposits — The ores of this class form a great group, analogous to the great group of stratified rocks. The name does not necessarily indicate that they themselves are stratified bodies, but that they are associated largely with the stratified rocks, and hence are amenable to the laws governing the elastic formations rather than those governing ore-formation. The case is one in which the accident of environment has come so largely into play that it has almost assumed the character of the dominant factor.

As most of these ores are introduced long after the enclosing country-rock has been formed, even those deposits which show a disposition to follow the general laws of stratification might be expected to be often erratic in occurrence. However, the genesis of ores of this kind is due to the action of the epigene geological agents. The containing-rocks are usually neither unduly indurated nor anamorphosed. When the ore-bodies of hypogenic origin occur in the sedimentary formations, or are found associated with those of the other class, they generally present characteristics that enable them to be readily distinguished. There is rarely confusion on account of this intimate association of the two groups.

The deposits of the eutaxic group seldom originate from heated waters rising from the depths of the earth. Whenever the latter do happen to spread out laterally along the bedding-planes of the stratified rocks, the area affected is rarely very extensive.

On the other hand, the real eutaxic ore-bodies most commonly originate while the country-rock is undergoing katamorphic change, while under ordinary epigene influences some constituents are being dissolved and carried away, and other mineral compounds, including those that are metal-bearing, are being left in their place. Hence, while such ore-bodies do not conform strictly to the bedding, or to the various structures of stratification, their distribution is, nevertheless, governed largely by the leading characteristics of the different layers of rock-materials.

Although not always clearly bedded in their relations to the rocks, the deposits of ores in caves, for example, still follow the stratification laws largely; for the caverns are usually opened out along the main stratigraphic planes, notwithstanding the initial crevice may have been immediately due to faulting or jointing.

The main geological function of most ores being that of space-fillers, the advantage of those deposits originating through epigene agencies over those produced by hypogenic means are very great, when the two come to operate in the same mass. The spaces in rocks, whether large caverns and underground passages, or minute granular interstices, are comparatively rapidly filled by the minerals held in solution in ordinary cir-

culating waters having no relations to the more heated depths. Moreover, metasomatic replacement goes on extensively under the same conditions. When mountain-making forces begin to act with comparative rapidity in a region, about the only spaces left to be filled by ascending heated waters are those along the fault-planes

Ataxic (Unstratified) Deposits.—In contradistinction to the other two groups mentioned, the ore-bodies of the unstratified or irregular group are usually associated in some way with igneous action. At any rate their origin is usually deep-seated, though not necessarily always so. Most often they have been forced to the surface in a more or less highly-heated condition. The association of minerals is peculiar and characteristic. When bodies of the stratified group resemble those of the igneous class, the paragenesis of mineral species is quite distinctive. While the formation of these ores is largely through solutions, the process is really more than ordinary solution. It is solution affected by heat, pressure and gaseous factors, which should have some distinctive title. For want of a better term, the name mineralization is, in the present connection, adopted for this purpose, in nearly the same sense as that in which this term is used in petrography.

Little or no relationship is observable between the deposits of this group and the geological structures of the surrounding matrix. The true fissures which these deposits most frequently occupy, follow lines dependent upon previous orogenic movements, but these are in no way connected with the original geological structure of the country-rock itself. Cavities dynamically formed may extend not only through massive rocks, but also continue through stratified layers as well. Certain cavern-accumulations in easily soluble sedimentary beds often very much resemble, at first glance, the true fissure-deposits; but there is usually little difficulty in discriminating between the two. In the past, many of the bitter controversies as to the igneous or aqueous origin of mineral-veins have hinged directly on this point.

SECONDARY CATEGORIES OF ORE-BODIES.

The immediate genesis of ores is in great measure chemical in character. The general phases of chemical activity, as controlled by physical factors, and the local conditions of geologi-

cal structure, furnish reliable and useful criteria for separating the metalliferous deposits into the great secondary classes

These secondary features harmonize with the primary criteria of ore-classification, and are readily correlated with the standards used in the ternary subdivision, which has as a basis the direct agency influencing the production of ore-bodies as geological formations.

While the criteria of these secondary groups are essentially chemical in nature, they are of such a character that they coincide closely with what we know as some of the great geological processes. In fact, as applied to ore-deposits, they furnish merely specific illustrations of broader and more general phenomena.

TERNARY PHASES OF ORE-DEPOSITION.

The third order of criteria, in the classification of ore-bodies, is that of specific genesis, as determined by the grander of the geological processes. For example, among the deposits formed as chemical precipitates on the earth's surface, there come to be recognized five phases :

- 1 Oxidation, ordinary.
- 2 Exhalation, from decaying organic matter.
- 3 Reduction, in presence of organic matter.
- 4 Evaporation, of carbon dioxide, for instance.
- 5 Secretion, of metallic salts by organisms.

So, also, in the case of surface ore-deposits transported and concentrated by moving waters, there are :

1. Thalassic, by the sea.
- 2 Fluvial, by rivers
- 3 Toriential, by flood-action on steep slopes.

In the present outline these ternary phases need not be expanded, and they are passed over without further comment.

TYPES OF HYPOTAXIC OR SURFACE-DEPOSITS.

The main subdivisions of the surface-deposits are three in number. Each of these has various special phases, which may also be considered in this connection. These ores may be regarded as formed through (a) aqueous transportation; (b) residual cumulation; or (c) precipitant action.

Aqueous Transportation.—We are accustomed to call the ore-deposits formed purely by mechanical means, placers. It is possible to recognize three quite different ways of formation. The chief method, as is well known, is by stream-action upon disintegrating rocks containing metalliferous constituents. In an analogous way, wave-action upon shores of seas and lakes often tends to separate locally the heavier from the lighter rock-materials, the former being frequently left behind as metalliferous sands. In favorable situations, the ordinary torrential work on hill-sides sometimes differentiates loose rock-materials into deposits sufficiently rich in metallic compounds to assume the character of ore-bodies.

Examples of this category are familiar. The most common deposits that have been mechanically transported are, of course, the native metals, gold and platinum. The gold-placers of California may be mentioned as good illustrations. They were first elaborately described by Whitney.* Penrose† has very recently noted similar placers in the Cripple Creek district of Colorado. Placers of the Urals‡ produce the greater part of the world's supply of platinum; though recently similar deposits have been reported from Northern California and British Columbia.

The stream-tin of Cornwall is the classic example of stanniferous minerals concentrated by river-action. Hanks§ also mentions analogous occurrences of stream-tin in Dakota, Idaho and California. Regarding the occurrence of iron as a stream-deposit, Penrose|| has lately called attention to the conglomerate limestone-ores of eastern Texas.

Wave-action and torrent-work are not, as a rule, important agencies of ore-accumulation. As instances of the former, the magnetite sands of Moisie, Quebec, may be referred to, and the gold-deposits of Cape Nome, and other parts of the Alaskan coast.

Residual Cumulation.—In the category previously mentioned, the metal-bearing rock-fragments are themselves transported. In the present case they are left behind, the country-rock being

* *Contrib. American Geol.*, vol. 1, 1880.

† *U. S. Geol. Sur.*, 16th Ann. Rept., pt. ii., p. 150, 1895.

‡ Tschernyschew, T., VIIth Cong. Geol. Int., *Guide des Exc.*, ix, 1897.

§ *California State Min.*, Fourth Ann. Rept., p. 120, 1884.

|| *Texas Geol. Sur.*, First Ann. Rept., p. 81, 1890.

removed either by mechanical means or by solution, or in both ways.

Many manganese-deposits are formed in this way. Penrose* has well described the braunite of Batesville, Arkansas, and Hall† the pyrolusite of the Crimora mine, in Virginia. The oxidized zinc-ores of the Bertha mine,‡ Virginia, partly originated by this method. Some of the limonite ores of Allamakee county, Iowa, as noted by Calvin,§ appear to be of the residual type.

The group is separable into a number of minor subdivisions, which, however, need not be considered in the present connection.

Precipitative Action.—The formation of ore-bodies by purely chemical means from solution in quiet waters is a wide-spread process. However, the deposits are usually quite limited in extent, and so, on the whole, rather unimportant. The bog-iron ores are the most common occurrences.

The ore-accumulations through precipitative action present several quite different phases. Most bog-ores, for example, are formed from chalybeate waters. Some of the North Carolina|| bog-ores may be cited. Direct exhalations of decaying vegetation cause local deposition of various metalliferous compounds. In a small way, the principle is illustrated by the limonite tubules in loess-deposits.¶ When ore-bearing solutions come into contact with organic matter, the latter often plays the part of a reducing agent. Wheeler** has described occurrences of this kind on a small scale, the material being zinc sulphide formed in the presence of coal (lignite?) Similar pockets of zinc-blende are also found associated with the coal of Morgan county, Missouri.

Evaporation is a frequent factor in enabling stable forms of ores to accumulate. Certain limonite-deposits of the Three Rivers district,†† in Canada, are produced in this manner.

* *Arkansas Geol. Sur., Ann. Rept.* for 1890, vol. 1, p. 99, 1891.

† *Trans.*, vol. xx, p. 46.

‡ Case, W. H., *Trans.*, vol. xxii., p. 511.

§ *Iowa Geol. Sur.*, vol. iv, p. 101, 1895.

|| Willis, B., *Tenth Census*, vol. xv, p. 302, 1886.

¶ Keyes, C. R., *Am. Jour. Sci.* (4), vol. vi, p. 299, 1893.

** *Trans. St. Louis Acad. Sci.*, vol. vii., p. 123, 1894.

†† Griffin, P. H., *Trans.*, xxi., 974.

Blake^{*} ascribes to this mode of origin the aluminum-ores at Silver City, New Mexico. The direct influence of microscopic organisms on ores is illustrated by the oolitic limonite-sands of the Swedish lakes †

The limonite-ores occurring at the Prosser mines,‡ near Portland, Oregon, are believed to have been formed in this way. Hayes§ ascribes to this origin the bauxite-deposits of the Coosa valley, in Georgia and Alabama; and Branner|| similarly accounts for the same kind of ores near Little Rock, Arkansas.

As examples of marine deposits may be noted the Eocene iron-ores of eastern Texas, as described by Kennedy;¶ and the Mesabi ores of Minnesota, first investigated by Spurr,** and considered to have occurred originally as glauconite.

ILLUSTRATIONS OF EUTAXIC ORE-BODIES.

Original Sedimentation.—The ores of this type include all former surface-deposits that have become buried, and are now interstratified with other sedimentaries. As surface-deposits their preservation is accidental. When covered by sediments they are governed by a set of conditions entirely different from before, and their exploitation is the same as for all stratified deposits.

The specular hematites in the Upper Marquette conglomerate,†† on the Marquette range in Michigan, appear to be partly of this type. Also part of the Iron Mountain hematite‡‡ in southeast Missouri. Native gold-deposits described by Turner§§ at Magalia, California, are ascribed to a similar origin.

Selective Dissemination —In some geological terranes, the ore-material is scattered through certain layers in small particles in such a way that, while the character of the rock is preserved, the metallic contents are sufficiently rich to be exploited. The

^{*} *Trans*, xxiv., 571

† Stapf, F. M., *Zeitsch der d. geol. Gesellsch*, Bd xviii, p. 86, 1866.

‡ Putnam, B. F., *U. S. Tenth Census*, vol. xv, p. 16, 1886.

§ *U. S. Geol. Sur.*, 16th Ann. Rept., pt. iii, p. 547, 1895.

|| *American Geologist*, vol. vii., p. 181, 1891.

¶ *Trans*, xxiv., 258.

** *Minnesota Geol. Sur.*, Bull. x, p. 258, 1894.

†† Van Hise, C. R., *Am. Jour. Sci.* (3), vol. xliii, p. 116, 1892.

‡‡ Pumpelly, R., *Bull. Geol. Soc. America*, vol. ii, p. 220, 1891.

§§ *U. S. Geol. Sur.*, 17th Ann. Rept., pt. i, p. 544, 1896.

ores are disseminated, as it were, through the country. Because of certain physical or chemical peculiarities of the rock, the metalliferous contents appear to have selected these layers and no others.

The present appearance of these ores in the matrix gives the latter the aspect of former marked porosity. This may or may not have been true. No doubt the porous character of the rock has had much to do with the tendency of the ore-materials to restrict themselves to limited zones, but the slightly different chemical composition of the successive layers or rock-zones has also played an important rôle

The variety of metallic substances occurring as ores in a disseminated condition that may be regarded as selective is considerable. Iron, lead, zinc and copper are the most common.

The disseminated lead-ores of southeast Missouri are good illustrations. Mine la Motte, Doe Run and Bonne Terre all present this form of ore-bodies. At the former mines, two principal productive horizons are recognized. The quantity of galena varies greatly, but is most abundant in the more porous layers.* The zinc-deposits of Franklin Furnace, N. J., may have been originally similar formations, that were afterwards metamorphosed.†

In the Lake Superior region, the native copper-deposits, passing downward at great depth into the sulphides, are found acting as a cement in limited, once porous, conglomerates,‡ and in altered scoriaceous diabase sheets.§ Blake|| notes that the antimony-deposits of Iron county, Utah, occur as disseminations in sandstones and conglomerates.

To a smaller extent, copper-ores in the form of cuprite, native copper and malachite are found scattered in small particles through sandstones, especially those of Triassic age, along the Atlantic border, and in Kansas, in this country; and in Germany, Russia and elsewhere, in Europe.

Emponded Amassment.—Ore-bearing waters may become ponded in a number of ways, depending upon the peculiarities of local geological structure, and may thus permit the ac-

* Keyes, C R, *Missouri Geol Sur*, vol ix., Sheet Rept. No 4, p 65, 1895

† Kemp, J F, *Trans New York Acad Sci*, vol xiii., p 76, 1893.

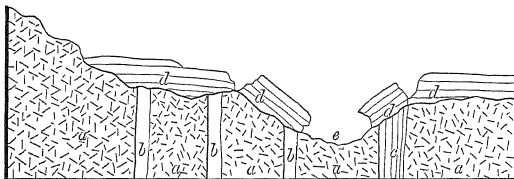
‡ Irving, R D., *U S Geol Sur, Mon* v, 419, 1883

§ Wadsworth, M E, *Bull Mus Comp Zool*, vol vii, 1880.

|| *U S Geol. Sur, Min. Res* for 1883-4, p 643, 1885.

cumulation of more or less important economic bodies. While in some cases amassment of this kind is to be considered as taking place under conditions producing surface-deposits, the reactions go on, in the main, without direct contact of the atmosphere.

FIG 1.

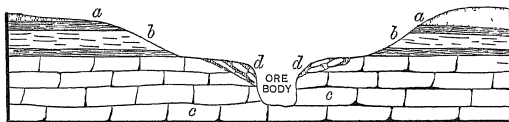


Ore-Bearing Basin of Unconformity, at Copper Basin, Ariz After Blake *a, a*, Granite, *b, b*, Dikes, *c*, Quartz, *d, d*, Sandstone, carrying Copper

The ores of iron are widely deposited in this manner. Some of the most noteworthy phases are noted below.

Along planes of unconformity, the basin-portions occupied by porous sandstones or basal conglomerates of the superior terrane afford conditions which locally interfere with the free circulation of waters. Blake* has described the malachite-ores

FIG 2.



Ore-Bearing Sink, at Cherry Valley Iron-Mines, Mo After Nason *a, a*, Sandstones in Place, *b, b*, Shales, *c, c*, Magnesian Limestone (real wall-rock), *d, d*, Disturbed Sandstones (apparent wall-rock)

of Copper Basin, near Prescott, Arizona, as presenting this kind of formation (Fig. 1). In this case the underlying granites, greatly decomposed, are traversed by many small mineral veins, some of which carry copper in one form or other.

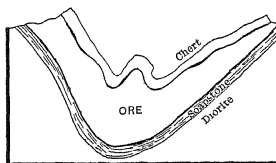
Former sinks in cavernous limestone-belts have often enabled considerable local bodies of sand and rock-fragments to gather,

* *Trans*, xvii, 479.

which afterwards became impregnated with ore-materials from standing waters. The Cherry Valley iron-mines, in south-eastern Missouri, are described by Nason* (Fig. 2)

In the Marquette district of Michigan, conditions of ore-deposition exist similar to those of the Penokee-Gogebic ore-bodies, but differently caused. The dike-cut strata are often folded sharply, so that either the sheets of dioritic trap or the impervious jasper layers form sharp synclinal troughs. In these the emponded waters finally drop their burdens. Van Hise's idea† is shown in Fig. 3. Smyth's account‡ of the hematites of Jefferson county, N. Y., indicates a like origin for these deposits. Here intrusions of granite or local flattening of the dips are believed to have an important influence in interrupting the free circulation of ore-bearing waters.

FIG 3



Ore-Bearing Syncline, in the Marquette Iron Range After Van Hise.

It is a well-known fact that miners, in districts of tilted stratified rocks, look for ore-deposits along the lines of faults, when these are known. A porous layer underlain by an impervious one is by faulting cut off, and on the same level replaced by a non-porous section. The circulation of waters is checked and the ore-materials are precipitated. Troughs are formed that are essentially like the Penokee-Gogebic form.

When impervious strata are cut by dikes and then tilted, troughs are formed which allow ore-laden waters to become quiet and then to deposit part of their burden. The hematite-ores of the Penokee-Gogebic range, south of Lake Superior, are remarkable examples. According to Van Hise,§ they lie

* *Missouri Geol Sur*, vol 11., p 134, 1892

† *Am Jour Sci* (3), vol xliii, p. 123, 1892.

‡ *New York Geol Sur*, 13th Ann Rept, p 498, 1894.

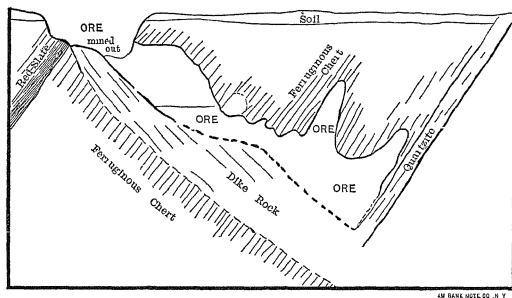
§ *Am Jour. Sci* (3), vol. xli, p. 117, 1891

in the angle of intersection of layers of compact northerly dipping quartzites and sheets of trap-rock having southerly dips. This arrangement is shown by the diagram, Fig 4.

Fold-Filling.—In regions in which strata are closely folded, differential movement of the layers produces at the apices of the arches and troughs cavities which become the receptacle of ore materials. Quartz or calcite masses are very commonly found in this position. The most notable ore-bodies occupying similar positions are the saddle-reefs of Victoria, Australia, as described by Schmeisser.*

Crevice-Accretion.—The metalliferous deposits of cavernous sedimentary rocks have been the crucial tests of the rival the-

FIG. 4



Ore-Bearing Trough in the Penokee-Gogebic Iron Range After Van Hise

ories of ore-genesis. Whether or not a given opening was filled from below by heated solutions, or was fed laterally by superficial waters, is a matter of small practical moment. In some cases they are undoubtedly formed in one way; in other cases, in the other.

As a rule, the crevices are opened out along joint-planes or faults of small throw. There is thus more or less regularity in their distribution and trend. While their vertical extent is often considerable, the broadest parts are restricted to certain definite layers, which were more susceptible to solution and chemical change than the other beds.

* *Gold Fields of Australia*, London, 1898.

The zinc-deposits of southwest Missouri, on the flank of the Ozarks, are examples in which the formations of caverns has been carried on to a wonderful degree Winslow's extended account* of them is the most accessible for details. The lead- and zinc-deposits of the Dubuque region in the Upper Mississippi valley are quite similar in all respects.† So also are the Mountain View mines of Maryland, described by Williams.‡

Gash-veins are largely of this type.

Concretionary Accumulation.—While this process is a common one among non-metallic substances, it is unimportant so far as it applies to ores. The clay-ironstone nodules of some shales are abundant enough in some localities to be of value. The nodular iron-ores of the Potomac clays, in Maryland and Virginia, have at one time or another furnished a considerable quantity of ore. The nodular black-band associated with the coal-beds of the Appalachian region also supplies some ore which is used, especially as a mixture with the more refractory varieties of iron-ore.

Metamorphic Replacement—In the metamorphism of rock-masses into crystalline schists a banded structure is superinduced. The various zones differing originally from one another in chemical composition, as well as physical character, retain in a measure certain notable differences. In the alteration of the original minerals, metallic replacements frequently occur, or conditions are induced which enable ores to be accumulated along certain zones. This gives rise to many of the fahlbands of the Germans. In the locality where this term was first introduced, at Kongsberg, in Norway, the various fahlbands contain ores of copper, iron, zinc and lead, as well as some silver and gold.

EXAMPLES OF ATAXIC, OR UNSTRATIFIED, ORE-BODIES.

Magmatic Secretion.—The basic masses which often crystallize out while molten magmas cool are frequently of sufficient richness, in metalliferous minerals, to constitute workable ores. The iron-ores are the principal occurrences. It is quite probable that many of these basic masses that occur so frequently in the

* *Missouri Geol. Surv.*, vol. vii, p. 543, 1894

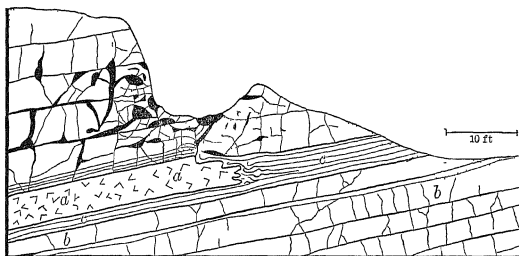
† *Bain, H. F., Iowa Geol. Surv.*, vol. x., 1900

‡ *Maryland, its Resources, etc.*, p. 148, 1893

eruptive rocks could be exploited with profit for some of the rarer metals. Excessively basic developments are known to occur in many marine rocks. Winchell* has called special attention to the existence of extensive ore-bodies of this kind in the gabbros of Mayhew, Portage, and neighboring lakes of Minnesota. More recently, in the Adirondack region, Kempt† has described similar ore-deposits of importance; while Vogt‡ has reviewed the many occurrences of Sweden.

Metamorphic Segregation.—In the alteration of the crystalline rocks by metamorphism there is, in addition to the formation of new constituents, a greater or less tendency for certain minerals to segregate and form ore-masses.

FIG 5



Copper-Deposits near Airlington, N J After Darton. *a, a*, Trap-Sheet, *b, b*, Sandstone, *c*, Shales The black represents seams and impregnations of copper ore

The chromite-deposits of Bare Hills, near Baltimore, Maryland, which are found in altered peridotite, appear to have been formed in this manner The nickel-deposits of the Gap Mine, in Lancaster county, Pennsylvania, described by Frazer,§ may have had a similar origin.

Fumarole-Impregnation.—The action of vapors in volcanic districts in forming ore-deposits cannot probably be separated from that of hot solutions. In most cases, both are in play at the same time On the borders of molten rock-bodies, fuma-

* *Minnesota Geol Sur*, 10th Ann Rept, p 80, 1882

† *Bull. Geol Soc America*, vol. v, p 222, 1894

‡ *Zeitsch f Prakt Geol*, Bd i, s 4, 1893

§ *Penn Geol. Sur.*, Rept. CCC, p 163, 1880.

role action is extremely active in metamorphosing the cold country-rock. Often, without completely destroying the identity of the country, ore-materials are deposited in the interstices and cracks. In this way considerable ore-accumulations are often made along the contact of the molten body of rock and the country.

The copper-ores found near Arlington, New Jersey, described by Darton,* appear to be chiefly impregnations, resulting from the cooling of an intrusive trap-sheet. (Fig 5) Some of the silver-ores of Mercur, Utah, noted by Spurr,† are also of the same category. Tin, in the form of cassiterite, seems to be the common result of fumarole-action in connection with granite.

Preferential Collection.—This method of segregation occupies about the same relation in the ataxic group as selective dissemination does in the eutaxic. While deposition of the ore-materials takes place mainly along lines of lithological similarity, and is usually associated with volcanic action of some kind, the ore tends to gather in more or less extensive and large bodies. In the cases of selective dissemination and crevice-accretion, the cavities and caverns were largely already existing when the ores began to be deposited. In preferential collection, the country-rock is largely removed at about the same time that the ores are left. The determining factor in localizing deposition is the mineralogical or lithological character of the country-rock, though fumarole-action often plays an important rôle. The deposits of this kind cannot always be well separated from regular contact-deposits.

As illustrations, several familiar mining districts may be noted. The lead-silver ores of Lake Valley, New Mexico, as described by Clark,‡ may be regarded as belonging to this category. The similar ores of Leadville, described so elaborately by Emmons,§ are also of great interest in this connection.

Fissure-Occupation.—The true fissure-veins, originating first by profound fracture and dislocation of the rocks, opening communication to deep-seated volcanic activity, are among the

* *U S. Geol. Sur., Bull.* 67, p. 57, 1890

† *U S Geol Sur., 16th Ann Rept.*, pt. 11, p. 367, 1895.

‡ *Trans.*, vol. xxiv, p. 138.

§ *U S Geol. Sur., Monogr.* xii, p. 378, 1886.

most familiar of the phenomena connected with ore-deposits. They need no special consideration in the present connection. It is convenient to recognize several more or less distinct phases. There are those originating, (1) along joint-planes; (2) along fault-lines, (3) along shearing-belts; and (4) in volcanic necks.

RECAPITULATION.

In considering the classification of ore-deposits, the main points which it is aimed to emphasize are .

(1) The chief feature wherein the present classificatory scheme differs from others is in the prominence given to geological occurrence, and the direct operation of the geological processes, as essential factors in the genesis of the ore-bodies.

(2) The nearest possible approach to a purely genetic classification of ore-deposits is believed to be found in their geological relationships, as determined by the great groups of geological processes, and not in their direct chemical formation or physical shapes.

(3) The chemical reactions so widely used as criteria of ore-classification are to be regarded as general agencies, and, therefore, they are not available in the specific determinations of the various classes of ore-bodies

(4) In the discovery and exploitation of ores, structure is of first importance, not so much the structure of the individual ore-body itself as the geological structure of the enclosing country rocks.

(5) The primary groupings of ore-bodies appear to be best indicated when based upon their geological occurrence, as governed by the nature of geological processes operating.

(6) The secondary groupings appear to be best based upon the general form of the ore-bodies as geological formations produced by the grander categories of geological agencies

(7) The ternary groupings are best based upon the specific phases of the geological processes involved in the formation of ores as ore-bodies.

(8) The source of the ore-materials is an unessential factor in their classification; the great practical question is, How are ores best exploited? In this connection it matters little what was the original condition of the ores. Nor have we to do very

much with the detailed, complex, and usually theoretical chemical reactions that are supposed to take place before the final stage of the ore, as we find it, is reached.

(9) Ore-bodies of very similar appearance may be formed by very different methods—a fact which, while apparent in all classifications, does not necessarily vitiate any.

(10) The present scheme is merely suggestive. It is the barest outline of what is believed to be capable of much further expansion and development into a comprehensive, rational and practical general plan.

The Clealum Iron-Ores, Washington.*

BY GEORGE OTIS SMITH AND BAILEY WILLIS, WASHINGTON, D. C.

(Washington Meeting, February, 1900)

I. SUMMARY OF GENERAL FEATURES.

Location.—The Clealum iron-ore deposits occur on Clealum river, a tributary of the Yakima river, in the eastern spurs of the Cascade range, Washington.† Mount Stuart, 9470 feet in altitude, is a dominant peak of the district, which will therefore be referred to as the Mount Stuart district. By way of the valley and cañon of the Clealum, the ores are 18 miles from Roslyn, the colliery-town, which is reached by a short branch from the Northern Pacific Railroad. Where they occur the valley has an elevation of 2900 to 3000 feet above sea; that of the end of the branch railroad at Ronald is 2345 feet. The grade of the valley from near Ronald to the junction of the Clealum and Salmon Lasac rivers, $14\frac{1}{2}$ miles, is 20 feet per mile; thence to the iron-ores it is 130 feet per mile, through a cañon $2\frac{1}{2}$ miles long. Abreast of the deposits the western wall of the valley is formed by precipices of sandstone; the eastern slope is comparatively gentle, being cut in easily eroded

* Published by Permission of the Director of the U. S. Geological Survey.

† The district is included in the Snoqualmie and Mount Stuart quadrangles of the Topographic Map of the United States, and the geology will be described in detail in the Snoqualmie and Mount Stuart folios of the Geologic Atlas now in preparation by the U. S. Geological Survey.

serpentine. The valley is floored with gravel, except where the iron-ore knobs project and in the channel of the stream. The mountains on either side rise 2000 to 4000 feet above the valley and are generally timbered.

Extent and Mode of Occurrence.—Outcrops of iron-ore appear at intervals along the valley in a single line from Camp creek to Boulder creek, a distance of 1 mile, trending S. 15° W. A distinct line of outcrops, extending about S 80° E., occurs a mile further south and high up in the spurs of the mountains east of the valley. These southern croppings lie from 650 to 1800 feet above those by the river and are traced for three-quarters of a mile.

The ore-bodies are lenses, which vary in thickness from a foot or two to 30 feet. They are not sufficiently exposed to permit a determination of their relations along the trend, but they appear at frequent intervals.

They have a definite geologic position in the rock-series of the district, and their distribution is determined by the geologic structure. They lie on the surface of an extensive formation of serpentine, at and in the base of a sandstone, called the Swauk sandstone. The serpentine is older than the sandstone. It had been much eroded when the sandstone was deposited, and the sandstone, although composed chiefly of granitic sand, contains in its lower beds, near the serpentine, bits of decomposed serpentine and heavy minerals derived from it. Limited lenses of shale composed of serpentine wash and also conglomerates of serpentine boulders occur at the base of the sandstone. Thus the surface on which the iron-ores occur was an eroded surface, which, with soil and other residual accumulations, was buried beneath granitic sands. The relations and character of the ore indicate that it was a sedimentary deposit on the serpentine, was covered by the sands, and later metamorphosed to its present condition.

Character and Chemical Composition.—The iron-ore is a greenish black, dull rock of amorphous appearance. It is characterized by the occurrence of numerous oolites in the structureless matrix. It contains both magnetite and hematite associated with more or less weathered serpentine, and the ore-lenses are composed of masses which vary from concentrated ore containing 60 per cent. or more of metallic iron to the clayey

waste of serpentine. The following table shows characteristic analyses:

	Samples Taken by Dr J P Kimball ‡		Sample Taken by Bailey Willis, Average of 350 Sq Yds exposed, approximate analysis, except for Fe, P and S	Monarch Mine, Average Sample in Pit Bottom Taken by Courtis and Smith †
	I Good Ore	II Poor Ore		
SiO ₂	3 10	14 40	7 5	8 950
TiO ₂	.		7	
Al ₂ O ₃	4 08	23 70	21 9	20 376
Cr ₂ O ₃	5 20	Undetermined	2 2	1 929
Fe ₂ O ₃	82 56	50 26	37 1	35 324
FeO	1 24	0 69	21 3	21 887
NiO	0 68	Undetermined	.2	. .
MnO	0 30	0.43	Undetermined a little	. .
MgO	1 01	1 02	2 3	0 720
H ₂ O	1 53	Undetermined	6 8	
P ₂ O ₅	.		.09	0.142
S	.	.	.03	0 130
CO ₂	.	.	15	
CaO	0 28	1 27		3 360
Ag.	.	.		trace
Au	.	.		trace
	99 98		100 27	
Metallic iron	58 77	35 16	42 51	41 737

The value of the deposit as an iron-ore depends, among other conditions, upon the degree of concentration economically possible in mining and hand-picking, the distribution of the phosphorus and other incidental constituents in the rock or ore, and the effect of the large percentage of alumina. In the leaner ore the alumina is greatly in excess of the silica, *i.e.*, is present apparently as a free oxide, which would be refractory in smelting. These questions, which belong to the province of the mining engineer and technologist, are not here discussed

II. GEOLOGY OF THE DISTRICT.

The general geologic character of the district is shown on the accompanying map.

Classification of the Rocks.

The Swauk sandstone, at the base of which the iron-ores occur, is known to be of Eocene age. Therefore, for this dis-

"Residual Concentration of Weathering as a Mode of Genesis of Iron-Ores,"
Dr James P. Kimball, *Am Geologist*, vol. xxi, p. 161, 1898

† Correspondence, published by permission of Mr Courtis.

cussion, the rocks of the district may be divided into two groups first, those which are older or pre-Eocene; and, second, those which are Eocene and post-Eocene. These two groups are separated by the unconformity at which the iron-ores lie. Each group includes several formations.

Pre-Eocene Rocks.—The oldest rocks of the area are slates, chert, limestone, quartz schist, and volcanic breccias and tuffs, constituting a pre-Eocene complex. All these rocks have been somewhat metamorphosed, yet rarely to such an extent as to prevent the determination of their origin. They were folded, sheared, and intruded by igneous rocks early in the history of the region, and have been more or less mineralized with cupriferos, auriferous, and argentiferous deposits.

One of the most voluminous of the intrusives in the pre-Eocene complex consisted of large masses of peridotite, now more or less altered to serpentine. These intrusive masses are scores of miles in length and several miles in width. They have in great part the form and relations of large dikes.

The youngest of the pre-Eocene rocks is a granodiorite closely resembling that of the Sierra Nevada. The rock looks like an ordinary medium-grained granite, except that it is poorer in quartz and slightly darker in color. It constitutes the Mount Stuart batholith, and that mass with others in the Cascades furnished the sands of the Swauk sandstone.

Eocene and Post-Eocene Rocks.—Arkose sandstones constitute the great mass of Eocene strata in the Cascade Range. They are of widespread occurrence on the west as on the east of the range. In the Mount Stuart district, the Eocene sandstones are divided by an extensive flow of basalt, and accordingly the Eocene formations are: first, the lower sandstone which is called the Swauk; second, the Teanaway basalt; and, third, the upper sandstone which is called Roslyn. The two sandstones are very similar in general character, and the eruption of basalt, which flowed from conduits now represented by innumerable dikes in the Swauk sandstone, appears to have occupied a brief interval, after which the conditions of erosion and deposition were essentially the same as before it.

The economically important facts of these Eocene rocks are the occurrence of a good grade of steam-coal mined at Roslyn, and the possibly valuable iron-ores at the base of the Swauk.

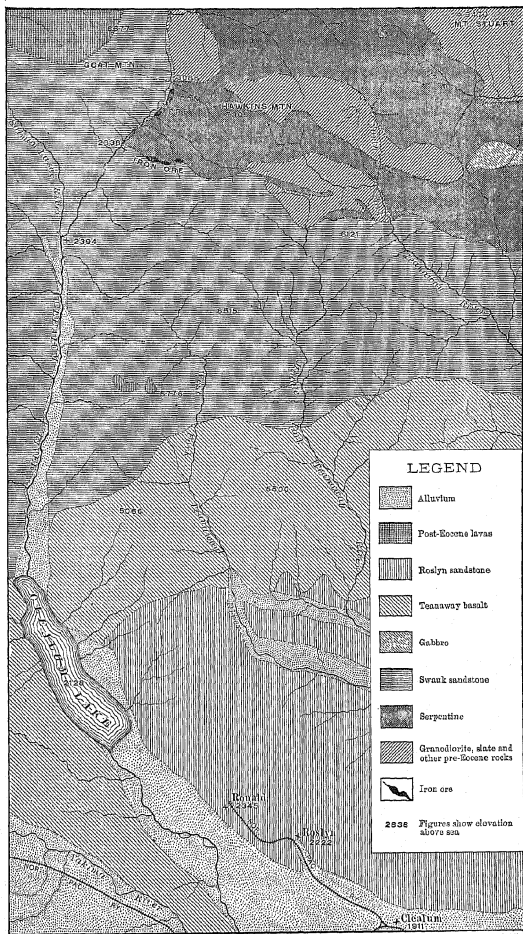
The Post-Eocene formations are of both sedimentary and volcanic origin. Basalt flows, younger than the Teanaway basalt, connect with basalts which form the great expanse of the Columbia plain far to the east. A complex mass of more acid volcanic rocks, chiefly andesitic, occurs in intricate relations with other formations about the headwaters of the Yakima river, and, overlying the Swauk sandstone west of the headwaters of the Clealum river, forms the summit of Goat mountain.

Geologic Structure.

Structure of the Pre-Eocene Rocks.—The pre-Eocene complex, the oldest series distinguished, is intrically folded, sheared and faulted. The details of the structure are not unraveled. The intrusive peridotite, now largely represented by serpentine, shared in the later experiences of deformation of the complex, and everywhere exhibits evidence of intense crushing and movement, which the soft character of the rock facilitated. The granite of the Mount Stuart batholith is much jointed, but never schistose. Its unmodified granitic texture and massive character distinguish it structurally from the older rocks, and prove that the deformation they exhibit had been in large measure accomplished before it was intruded.

Structure of the Swauk Sandstone.—The Swauk sandstone was bent with the underlying rocks and some of the overlying strata during the late Eocene or early Miocene. The date is not well determined, and the movements may have occurred at two or more distinct epochs. The essential result in the vicinity of the Clealum iron-ore deposits is an anticlinal fold. The anticline is apparent in the attitude of the Swauk sandstone, which at the ore-deposits in the valley and west of them in Goat mountain strikes a few degrees west of south and dips 45 degrees west, but which strikes S. 80° E. and dips 75 degrees south in the vicinity of the other iron-deposits a mile further southeast. The axis of the anticlinal arch is cut in the cañon of the Clealum river, and the base of the Swauk formation has been traced in its swing around the axis from the western to the southern dip. The pitch of the axis is toward the southwest.

A small fault is seen in one exposure of the iron-ore in the southern outcrops high up on the hill. It is a normal fault,



Geologic Sketch-Map of Clealum District, Washington.

striking N. 17° W. and having from the vertical 15° W., with a vertical throw of about 60 feet. Northward this fault is not determinable, since, if it exists, its position coincides with Clealum valley, and it is obscured by superficial gravels. It is here referred to chiefly because Dr. Kimball has described the structure of the deposit as that of a faulted dome.*

III. HYPOTHESES.

Genesis of the Ore.

Source of the Iron—The iron concentrated in the hematite and magnetite of the ore may be of extraneous origin or derived from an adjacent rock. In the facts of its position and association there is no evidence to show that it is a deposit brought in from any more or less remote extraneous source. There is much, on the contrary, to connect it with the serpentine. In its field-relations the ore lies on the serpentine, contains serpentine waste, and grades into shale derived from serpentine. The analyses of the ore and serpentine (p. 364) show that they both contain, in addition to the usual rock-constituents, such occasional ones as chromium and nickel. Magnesia, an important constituent of serpentine, is also found in the ore. It is therefore reasonable to suppose that the iron-ore is a result of concentration from the serpentine.

Conditions of Deposition—The iron-ore occurs on a surface of unconformity, the surface of the serpentine formerly exposed to the weather and later buried under sands of the Swauk formation. In order to frame a hypothesis of the conditions of concentration, it is necessary to interpret the facts of the unconformity.

The basal-beds of the Swauk formation, other than the relatively limited occurrences of iron-ore, are generally coarse arkose and more locally conglomerates, which consist of granite, greenstone, and slate pebbles mixed, or of serpentine boulders alone, or rarely of granite boulders alone. The conglomerates are exceedingly local in extent, and when composed almost wholly of serpentine or granite are restricted to areas of those rocks underlying. The serpentine conglomerates contain only occasionally a granite pebble or one of any other rock

* *Op. cit.*, p. 157.

than serpentine. The granite conglomerates contain a larger, but yet surprisingly small, proportion of slate or quartz pebbles.

These facts, taken in connection with the enormous volume of arkose which constitutes the Swauk and Roslyn formations, indicate that the conditions limited the transportation of boulders and shingle, but favored the accumulation of granitic sands, and, furthermore, that the localities where serpentine was weathering were for a time protected from the invasion of the wide-spreading deposit of arkose.

The basal contact of the Swauk with the older formations is exceedingly uneven, and when traced out reveals the bold relief of the Eocene topographic surface, in which the soft shattered serpentine corresponded with lowlands. Those depressions, which received little or no wash of other rocks than serpentine, may have been water-sheds limited to areas of that rock. Here meteoric waters leached out the soluble parts of the disintegrated rock, and the mantle of residual material was deep. The climate was sub-tropical and vegetation abundant.

As the coast of the rising water-body of early Eocene time was established it assumed a very irregular outline, with numerous bays and promontories. The climate became favorable to very rapid disintegration of the granite, probably through slight hydration of the feldspar, without marked chemical change. At certain points along the coast, streams delivered the granite waste, which was built into beaches, spits and bars by shore-currents. Behind the beaches and spits, lagoons were enclosed, and, in some instances, such lagoons corresponded to shallow bays which received the drainage from areas of serpentine. That drainage was charged with iron and with decaying plants. The conditions were thus favorable for precipitation of iron either as ferrous carbonate or as a hydrate of the sesqui-oxide in the shallow waters of the lagoon. As the shore-line of the slowly rising water-body advanced upon the land, the several conditions advanced with it, and in favorable localities a deposit of iron was a characteristic, and more or less extensive, basal deposit of the sediments. The conditions are believed to have been closely analogous to those which accompanied the deposi-

tion of the carbonate-ores that have been dug in the Cretaceous formations about Baltimore, Md.

Chemical Relations.—In connection with the hypothesis that the ore is the product of decay of the serpentine, a comparison of the analyses of the two is essential. The serpentine, of which the following is an analysis, was collected at some distance from the Clealum river locality, but fairly represents the rock at that point. It is here compared with the average sample of the ore taken by Mr. Willis.

	Serpentine Per cent	Ore Per cent
SiO ₂ ,	39.	7 5
TiO ₂ ,	trace	7
Al ₂ O ₃ ,	1.75	21 9
Cr ₂ O ₃, . . . . .	.47	2 2
Fe ₂ O ₃ ,	5 16	37 1
FeO,	1.71	21 3
MnO, . . . . .	.15	trace
MgO,	38.	2 3
H ₂ O,	13.74	6 8
K ₂ O + Na ₂ O, . . . . .	.10	undet.
P ₂ O ₅ ,	trace	.09
NiO, . . . . .	.10	.2
S, . . . . .	.03	.03
CO ₂ ,	none	.15
	<hr/> 100 21	<hr/> 100.27

In comparing these two analyses, we may consider the lean ore as a rearranged, but chemically little modified, residual product of the serpentine. In such comparisons most students of the subject of weathering have regarded alumina as the constituent least liable to removal, and therefore best adapted to serve as a basis of calculation. Supposing none of the alumina to have been lost in course of the weathering of the serpentine, the alumina present in the residual product furnishes a measure of the amount of concentration involved in the process, and also of the amount of the material removed. In the present case, the alumina percentage having increased from less than two to nearly twenty-two, it would follow that twelve and one-half units by weight of the serpentine were required to furnish one unit of the residual deposit. Calculating the losses for the principal constituents, it is found that the material removed has been in the main silica, magnesia and water. The approximate

losses suffered by these constituents expressed in percentages are 96, 99 and 96 per cent respectively. There is no apparent loss of ferrous iron, but in view of the probable interchanges of the two oxides of iron, the result may perhaps be expressed in terms of the iron itself, which shows a loss of 31 per cent. in the course of the decomposition of the serpentine into the residual product. There were also small losses of manganese, chromium, phosphorus, nickel and the alkalis, many of these losses being large if expressed in terms of the amount present in the serpentine.

The amount of concentration here calculated may seem very hypothetical, and the consequent loss of material in the formation of a residual deposit too great to be reasonably entertained. Merrill,* however, cites a case of weathering of serpentine into residual soil, in which the increase in alumina indicates a concentration of nearly thirty to one. Calculations based upon his analyses of the serpentine and of its residual soil show the silica, magnesia and iron oxides to have lost approximately 95, 99 and 96 per cent. respectively. The two cases are thus comparable, except that in the residual soil, just mentioned, the residue of silica is sufficient in amount to allow the alumina to be present in the usual state, the hydrous silicate. In the Clealum ore, however, there is silica for a small portion only of the alumina. The large remainder must be present as a free oxide or hydrate, probably such as that which forms bauxite.

The Clealum ore resembles in a general way some of the more ferruginous bauxite-ores, and, as has been seen, it also occurs with the same relations to a basic rock that the German bauxites show to basalt. The chief difficulty in assigning a residual origin to this deposit is a chemical and not a geological one. The problem is to account for the disassociation of the silica and the alumina. However, the same difficulty inheres in the cases of the German bauxite-ores, which are plainly residual in origin. Merrill gives the analysis of a residual clay derived from an argillite in Maryland, which shows an excess of alumina, only one-half enough silica being present to combine with the alumina. This loss of silica seems peculiar, but this case also must be considered as showing that some of the

* Merrill "Rock, Rock-Weathering and Soils," p 226

most common reactions of weathering processes have not yet been traced.

The reactions begun in the alteration of the original peridotite into the serpentine were doubtless continued in the process of weathering, the magnesia being removed as carbonate, together with some of the iron, while silica may have been set free in the chalcedonic state. Such is the process as usually observed in the weathering of serpentine. It seems probable that the residue from the decomposed serpentine was composed principally of the hydrated oxides of aluminum and iron. The former may at this time have been segregated in the concretionary form so characteristic of bauxite deposits. Similar concretions in iron-ores have been shown by Van Hise* to indicate metasomatic derivation from the iron carbonate. The carbonate may have been either the original or a later form of the iron in this deposit. Organic matter was without doubt present in sufficient amount to account for the formation of the carbonate.

The original deposit of aluminous iron-ore has been metamorphosed in consequence of deep burial, and of movements suffered in the deformation of the region. The plane of contact of the Swauk sandstone on the serpentine may have been the course of waters which oxidized or reduced the ores from their original state to their present condition. Diaspore, which occurs in the ore in small quantities, may have resulted from a partial dehydration of the bauxitic material present. Rutile and chromite are minerals also present in small quantities. Whether desilicification has continued during this second period is uncertain, but the presence of solutions containing free silica is indicated by the filling of minute cracks in the ore with what appears to be chalcedonic material. The ore and its relations have not been studied sufficiently to determine the nature of the metamorphism.

* *Monograph* xix, *U. S. Geol. Sur.*, p. 209.

The Cripple Creek Volcano.

BY T. A. RICKARD, STATE GEOLOGIST OF COLORADO, DENVER, COLO

(Washington Meeting, February, 1900)

THE Cripple Creek district occupies a cluster of foot-hills on the south side of Pike's Peak and is a portion of an extensive, though uneven, plateau which unites the eastern range of the Rocky mountains with the Sangre de Cristo. It is essentially a small volcanic area, of about 20 square miles, amid the granite of the Front range. But though, when regarded as a rich mining district, it may be considered as an isolated area,* yet, geologically, it is, as Whitman Cross has pointed out, only an outlying portion of a much larger volcanic region,† which stretches to the south and west, around Silver Cliff and the Rosita hills, forming the picturesque country cut by the deep cañons of the Arkansas river and its tributaries.

The mines are situated amid a volcanic complex, consisting of tuffs and breccias which have been penetrated by an extensive system of dikes and other intrusive masses. The prevailing formation is an andesite breccia, which lies upon the worn surface of the granite and fills the deep basin around a volcanic vent. The breccia, since its deposition, has been broken into by several eruptions of phonolite and, later still, by a series of thin dikes of basalt and other allied rocks of a highly basic composition.

The successive sedimentary formations which, elsewhere in Colorado, lie upon the basal granite, are not represented in the district; whatever sediments were laid down before the volcanic period must have been removed by erosion, and there is very little evidence which affords a datum-line whereby the geological age of the volcanic eruptions can be determined. Whit-

* The main mining belt of Colorado is 30 or 40 miles to the west, and extends through Boulder, Gilpin and Summit counties, into Leadville, and then south-westward, through Aspen, into the San Juan region

† "Geology of the Rosita Hills, Custer County, Colo.," by Whitman Cross *Proceedings of the Colorado Scientific Society*, vol. III, Part III, p. 269, 1890

man Cross has referred the breccia* of Cripple Creek to the close of the Eocene period or to the early Miocene.† This is done by correlating the small deposit of grit which occurs on Straub mountain, and is the only sedimentary formation in the district, with the lake-beds at Florissant, 15 miles to the north. These celebrated fossil-beds belong to the late Eocene, they are largely made up of volcanic dust and are covered by breccia similar to that of Cripple Creek. Moreover, they are overlain by rhyolite identical in character with that which forms the floor of the gravel-deposit on Straub mountain

The granite which forms the basal rock of the region is usually described as Archean. It is probably Algonkian. It is, elsewhere, overlain by Upper Cambrian strata; and it has been found to include fragments of quartzite which are believed to be of pre-Cambrian or Algonkian age. Therefore the granite is not necessarily Archean, but, to quote Dr. Cross, "older than the only Cambrian rocks as yet identified in Colorado"‡

Within the Cripple Creek area the granite differs in appearance from the rock which generally prevails in the Pike's Peak region. It is a well defined reddish biotite (black mica) granite, and, instead of the microcline (feldspar) which ordinarily characterizes the Pike's Peak formation, it carries orthoclase in prominent tabular crystals.§ The quartz is usually

* The miners call the breccia "porphyry" This term is derived from the Greek word "porphyra," meaning purple. It was first applied to the beautiful dark-red rock which the Romans obtained from the quarries of Ghebel Dokhan, near the shores of the Red Sea. This original "porphyry" would now be classed as a porphyrite. However, the original name, which depended upon color, has long since lost its force in another meaning, which refers to the structure. The original "porphyry," according to Zirkel, was speckled with snow-white and rose-red crystals of feldspar in a blood-red ground mass. Hence the term became applied to rocks in which some particular mineral, frequently feldspar or quartz, stands out well defined from the general matrix, giving it a spotted look, as for example in the familiar "bird's-eye porphyry" of the western mines. The term is often employed as though it covered a particular species of rock, while in fact it is merely a descriptive adjective-noun, covering any kind of crystalline rock having a mottled appearance due to the predominant development of one of its constituent minerals in individual crystals.

† "Geology and Mining Industries of the Cripple Creek District, Colorado," by Whitman Cross and R. A. F. Penrose, Jr., 16th Ann. Rep. U. S. Geol. Surv., Part II, p. 18, 1895. The writer owes a great deal of his descriptive geology to this valuable monograph.

‡ *Op. cit.*, p. 17.

§ I obtained some fine twin crystals (Carlsbad type), 2½ inches long, from the top of Bull Hill.

iron-stained, and the mica shows the commencement of a change into green chlorite. The oligoclase, which occurs as a subordinate feldspar, shows a ready tendency to decomposition, especially near the ore-bodies in the mines.

Turning to the examination of the breccia,* we find that it consists of a consolidated mass of fragmentary material having a coarseness comparable to gravel. Occasionally the pieces are as large as a man's hand; but these are rare. More frequently the breccia is very fine, and then comes under the designation of "tuff." It is mainly composed of augite-andesite, in which smoky-brown prismatic crystals of apatite occur. The feldspar is kaolinized, and the dark silicates, such as augite or biotite, have undergone destruction by leaching. While the mass of this formation is made up of andesite, it exhibits, locally, a good deal of fragmental phonolite and granite, the latter more particularly in the vicinity of the contact. Fine pyrite is distinguishable in most specimens. In the upper workings of the mines the kaolinization of the feldspar has given the rock a bleached appearance, and at the surface the iron oxides, derived from the alterations of the pyrite, have stained it yellow or red. Fluorite is a frequent constituent, wherever the breccia is penetrated by the gold-bearing veins, and colors it a dark purple. The finer tuffs are often so silicified as to be undistinguishable, except under the microscope, from massive rocks. The decomposed breccia also exhibits the healing effects due to the infiltration of secondary quartz; and, when it is included within the boundaries of any of the ore-deposits, the soluble ingredients have been removed to such an extent as to leave often only a pumice-like remnant of inter-lacing quartz.

Penetrating the mass of the breccia and extending into the surrounding granite, there is an intricate series of dikes, chiefly of phonolite † This is usually a light-colored rock of even

* "Breccia" and "tuff" are both words of Italian origin. We owe many terms describing volcanic materials to the study of Vesuvius. "Breccia" means "broken." It is applied to rocks made up of a consolidation of angular fragments. "Tuff" is employed both for a rock built up of fragmental material of smaller size than that composing a "breccia," and also for the rock resulting from the mud caused by the action of water upon volcanic dust. In the latter sense, the original Italian word "tufa" is made use of by many authorities.

† "Phonolite" is derived from the Greek words "phone," sound, and "lithos," stone. The close texture and even grain of the phonolite causes it to give a ring-

texture and sherd-like fracture; but the conditions of its occurrence, in thin and in thick dikes, in almost horizontal sheets, and in shapeless intrusive cores, are so varied as to have induced a great many modifications in its physical characteristics. The essential constituents are sanidine (the glassy variety of orthoclase) and nepheline. The crystals of the latter are occasionally sufficiently developed to give the rock a porphyritic appearance. Besides the normal phonolite there are allied rocks, such as trachytic* phonolite and nepheline-syenite,† occurring under various structural conditions. There are also dikes of andesite,‡ similar in character to the earlier rock which, in its fragmental form, composes the bulk of the breccia. Finally, crossing these rocks, and therefore last in the sequence of eruption, are the dikes of nepheline-basalt with which important ore-bodies are associated on Raven hill and Battle mountain.

The Cripple Creek district represents the ground-floor of a volcano,§ the superstructure of which has been removed by erosion. Let us consider what this means. Among the gains of modern science there is none more striking than the elucidation of the causes which bring about the terrifying phenomena of volcanic action. A hundred years ago, an active volcano excited superstitious fear, and was regarded only as a catastrophic interruption to the order of nature. Since then, the patient researches of such men as Spallanzani, Scrope and Judd have enabled us to recognize in these activities the orderly operations of forces subject to definite laws.

ing sound when struck with a hammer. In England it is often called "clinkstone."

* "Trachyte" is from the Greek word meaning "rough." The rock usually has an uneven fracture, due to the angular sanidine and the porosity of the ground-mass.

† "Syenite" comes from the Greek Syene, the town in Egypt now known as Assouan. It is a curious fact that it has, comparatively recently, been found that the rock at Assouan is not a typical syenite, which is a variety of granite containing very little quartz, with hornblende replacing the mica. It is really a red granite, very much resembling that of Pike's Peak. The Egyptians quarried it for their obelisks, and out of it they built the Temple of the Sphinx at Ghiseh.

‡ "Andesite" is derived from Andes, the mountain range in South America where it is particularly prevalent.

§ The word "volcano" is Italian. It was the name given to one of the Lipari Islands in the Mediterranean, where quiet eruptive action has been going on since the time of the ancients, who considered the little mountain-island as the forge of the Roman god Vulcan.

The scope of scientific investigation has included not only the observation of existing* volcanic action, but also the examination of the remains of extinct volcanoes. The structure of the latter has thrown light on the behavior of the former. As the story of the development of forms of life now extinct, but preserved in fossil-beds and recorded for us by the palæontologist, advanced our insight into the structure of living things, while biology repaid the aid thus received from palæontology by contributing the clues through which the incomplete evidence of the rocks was so correlated as to demonstrate the sequence of strata, so the study of the volcanoes of to-day led geologists to recognize the results of similar action in masses of rock, the eruptive origin of which was previously unsuspected, and, in turn, the deciphering of the skeletons of extinct volcanoes advanced the understanding of those which have survived. Natural sections gave the requisite testimony. Atmospheric erosion, acting through vast periods of time, has cut into the mass of many of the ancient volcanoes of the earth so as to uncover their anatomy. The dissection, by Professor Judd, of the old volcano of Mull,† in the Western Isles of Scotland, is an excellent example of this method of research. Occasionally mine-workings, or excavations made for other purposes, afford valuable evidence as to the internal structure of volcanic mountains. The Kammerbuhl, in Bohemia, is a curious instance‡. It is a small hill, apparently of no particular interest, but, nevertheless, it was once the subject of a hot scientific discussion. The poet Goethe took part in the dispute, and persuaded a friend, Count Sternberg, to drive a tunnel into the hill with a view to settling the question of its origin. The result justified Goethe's claim that it was "a pocket edition of a volcano." It was found that the hill consisted of a mass of volcanic scoria,§ through the center of which passed a plug of basalt. The plug obviously occupied the choked-up vent of the volcano, from which proceeded a lava-stream which had flowed over the flank of the hill. Fig 1 illustrates this statement

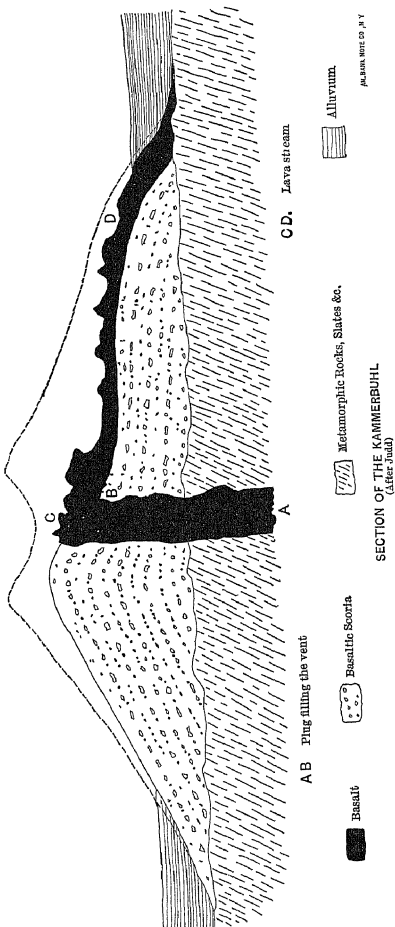
* There are about 350 active volcanic vents on the surface of the earth at the present time

† *Quarterly Journal of the Geological Society*, vol xxx, p 220, etc

‡ See Judd's "Volcanoes," pp 112-114

§ "Scoria" is a Latin word, unchanged. It is used especially for coarsely vesicular lava, but often for fragmental lava in general.

FIG 1.



At Cripple Creek, the mine-workings afford a good deal of information concerning the underground structure of the region. It is hoped that an inquiry into the history of the volcano which determined the interesting character of the district will contribute towards a clearer comprehension of the geology of the mines.

The operations of nature in the past are inferred from the observation of those which take place to-day. The intensity may vary, the forces are the same. This is the corner-stone of modern geology as laid down by Lyell. The volcanic complex at Cripple Creek is to be understood in the light of the evidence gathered for us by the patient investigators who have stood by the side of the craters of Stromboli, Vesuvius and Kilauea.

The conclusions of those who have made a specialty of this branch of geology* may be summarized thus: The explosive violence of volcanic eruptions is due to the access of water to the fused rock within the conduit of the volcano; but, as it appears that this water is not contained within the substance† of the lava‡ emitted during the tranquil emissions succeeding the first paroxysmal outburst, it is inferred that the water is not the primary cause of volcanic action, which originates at a depth greater than that to which it is believed that water can penetrate. The evidence collected is not complete; but it warrants a reasonable conjecture that volcanoes owe their origin to the contraction, caused by the cooling,§ of the earth's crust upon a yielding substratum, separating the solid outermost shell from an equally solid nucleus.|| While, therefore, the force which

* Among the best literature on the subject may be mentioned *Volcanos* by Poulett-Scrope, *Volcanoes* by Judd, and *Characteristics of Volcanoes* by Dana.

† That is, "occluded"

‡ Lava is Italian for "stream" It is from the same Latin root as lave, lavatory, etc. Although the term is usually applied to the fused material emitted by a volcano, it is often employed in referring to the same rock after it has become consolidated, especially when the rock has not been specifically classified.

§ "Seeular refrigeration"

|| The question of the condition of the earth's interior is too large for extended reference. Besides the standard text-books on geology, the reader will find much suggestive matter in Osmond Fisher's "Physics of the Earth's Crust," and in Prestwich's "Controverted Questions of Geology." There is also a summary of the evidence regarding this subject in the address of Sir William Thompson (Lord Kelvin) before the meeting of the British Association in 1876. The general conclusions of science have been lately expressed, in a popular way, by Pro-

pushes large quantities of fused rock to the exterior of the earth has, probably, a deep-seated origin, nevertheless, the immediate cause of the uncertainty, the violence and the magnificent energy of volcanic action is traceable to the effects produced by water coming into contact with the lava as it approaches the surface.

The destructive energy of a volcano may be likened to a boiler-explosion, volcanoes may be considered the safety-valves of creation. The mass of incandescent rock which is slowly being squeezed upward meets a large volume of water which flashes into steam with a sudden expansion causing the most astounding results. One cubic foot of water yields 1700 cubic feet of steam. It is accepted by specialists that, whatever the ultimate origin of volcanic action may be, the surface effects are due to the explosive escape of accumulations of steam suddenly released from pressure. This explanation is based upon accurate observation of the quiet workings of the miniature volcanoes of the Lipari Islands, in the Mediterranean, and upon the evidence obtained during the more violent, apparently paroxysmal, outbursts of Vesuvius, Etna, Tarawera, Kilauea and Krakatoa.

The volcanic rocks of the Cripple Creek district have come up through the granite. It underlies them all, they rest upon it, and can be seen penetrating it in the form of dikes. Previous to the first eruption, the granite must have presented a weather-worn surface, such as characterizes the high hills. Ever since its first emergence from the ocean this region has been undergoing an intermittent elevatory movement, which culminated in making the Front range. Erosion had been continuous, but the uplift more than counterbalanced such wearing away; and the granite hills had been slowly raised far above the Cretaceous seas which washed their edges in the era preceding that to which the eruption is assigned. The forces which had done this work were of the most patient kind, their

fessor Milne, thus "The earth became solid under two influences, it began to solidify at the surface by cooling, the crust growing thicker and thicker, and it began to solidify at the center by pressure, the core growing larger and larger. This double phenomenon of solidifying continued until a solid outer shell and a solid inner core came close together in what may be called the critical region of the earth, the region which feeds lava to volcanoes "

manifestation had about it nothing of a violent or paroxysmal character, time was an essential element of the process

At the close of the Eocene period this apparent equilibrium was disturbed. The foundations of the granite hills trembled. Slight tremors were followed by earthquakes, and these were the precursors of greater violence.

Earthquakes usually precede an eruption. In certain volcanic regions, such as the north island of New Zealand and Japan, the minor shocks, designated as "tremors," are of daily occurrence. They represent the vibrations set up by the sudden generation of steam from water coming into contact with the upwelling lava. It is water-vapor, and not smoke, which is emitted by volcanoes.[†] This water is derived from the surface, having sunk into the soil, permeating the more porous sedimentary rocks, lodging in the crevices of unstratified formations, and becoming stored underground, as mine-explorations testify. Where the country surrounding the volcanic vent has become covered with the products of previous eruptions, the loose character of the soil, resulting from the disintegration of scoriaceous lava, facilitates the descent of the rains, and tends to the accumulation of large quantities of water. Moreover, the vibrations set up by the superheated steam cause fissures which allow distant bodies of water, from subterranean reservoirs, fresh-water lakes,[‡] or, if the volcano be situated near the coast, the ocean itself, to be let down[§] suddenly into the volcanic vent and into explosive contact with the incandescent lava. Humboldt[§] found small fishes in the water

[†] Volcanoes are not necessarily mountains. The mountain is the result of the volcano, and not *vice versa*. It is the accumulation of the material ejected from the vent which slowly builds up the cone. Many emissions of lava occur at the base of mountain ranges and have quietly overspread the surface from fissures, much as water rises through cracks in the ice and overspreads it, when a heavy wagon presses it down. The lava-plains of the Snake river, traversing Oregon and Idaho, afford an example, so does the Deccan (India), where successive, nearly horizontal, flows, covering an area of 200,000 square miles, have reached a thickness of 6000 feet.

[‡] Lake Rotomahana was drained at the time of the eruption of Tarawera, in New Zealand, in 1886.

[§] Mosely (*Notes by a Naturalist on the Challenger*, p. 503) mentions that, in 1877, when on board the "Challenger," he saw the sea-water actually pouring down into a fissure formed in the bed of the sea off the Hawaiian coast. The fissure was traced to the shore and three miles inland. This occurrence was connected with the volcanic activity of Mauna Loa, on the neighboring island of Hawaii.

[§] *Convergent Questions of Geology*, Prestwich, p. 116.

emitted from fissures caused by earthquakes in the Andes. Diatoms, the microscopic forms of life characterizing the deep sea, have been found in the volcanic ejections of the Pacific islands. Where volcanoes are in proximity to the ocean it has been found that among the emanations from the lava there exist, not only chlorides, but also sea-salt itself. A sudden diminution of the water-supply in wells and springs near Naples has been repeatedly observed to presage the eruption of Vesuvius.

There is therefore ample evidence that water does penetrate into the conduit of the volcano, and that it is originally derived from the surface. As against the contrary belief, namely, that the water-vapor accompanying eruptions is an essential constituent of the lava, and therefore shares with it a deep-seated origin, there is the following evidence. It has been found, as the result of a large number of accurate observations in wells, shafts and bore-holes, that the temperature underground increases 1° F. for every 48 feet of descent.* At 7776 feet, the boiling-point, and at 34,700 feet, the critical point, 773° F., of water, would be reached. The expansive force of steam increases rapidly with the temperature, so that at 773° F. it would be equal to the pressure of 350 atmospheres.† This is termed the "critical point," because, at this temperature, water, however great the pressure to which it is subjected, can no longer exist as a liquid, but becomes dissociated into its constituent gases. Although the exact conditions which obtain at these great depths cannot be known with certainty, nevertheless, all the evidence goes to show that there is a limit set to the descent of surface-water by the rapid increase in the expansive force of its vapor, due to the rising temperature. Prestwich‡ put the maxim limit at 6 to 7 miles, and Delesses§ estimated it

* "On Underground Temperatures," Sir Joseph Prestwich. *Proceedings of the Royal Society*, February, 1885. Of course this increment of 1 degree per 48 feet can only apply to the outermost portion of the earth. Beyond a few miles of depth there must exist conditions of which very little can be inferred. There, the enormous pressure probably counteracts the expansive effects of heightened temperature, and upsets many of the conclusions of physics which hold good near the surface.

† Which, at 15 lbs. per square inch for each atmosphere, amounts to about $2\frac{1}{2}$ tons per square inch.

‡ *Controversial Questions of Geology*, p. 93.

§ *Bulletin Société Géol. de France*, vol. XIX, p. 64.

at 60,000 feet, or about 11 miles. Moreover, experience goes to show that the water encountered in mines is the drainage from the surface. Deep mines are usually dry ones. I may instance the deepest metal-mines, the Calumet-Hecla and Tamarack, in the Lake Superior region, and the "180," "New Chum-Victoria," and neighboring shafts, at Bendigo, in Australia.

The evidence obtainable concerning the first eruption of the Cripple Creek volcano is necessarily very meager. The first vent must have been formed at some point along one of the fractures caused by the earthquake-shocks; the lava, in forcing for itself a way to the surface, being aided by the force of the expanding steam. The pressure required to break a passage through the overlying rocks is stupendous, and, as a consequence, when the steam accompanying the lava is finally, and very suddenly, released from that pressure, on its immediate arrival at the surface, it escapes with explosive energy, and with projectile discharges which may reach to an astonishing height. Thus, when the outburst of Krakatoa, an island near Java, occurred in 1883, the finer fragments ascended skyward 10 miles, and were recognizable* in the atmosphere of London. The winds carried the dust of Krakatoa round the world, and thus gave rise to the extraordinary sunsets observed in the autumn following.

The material ejected during the first outburst of a volcano consists of fragments of rock torn from the sides of the vent. The extinct volcano of the Kammerbuhl, already mentioned in this paper,† exhibits pieces of burnt slate within the mass of the scoria forming its cone. The underlying formation consists of slates and other metamorphic rocks.

The Cripple Creek volcano first ejected fragments of granite. These were probably small in size, and became further reduced by colliding with each other as they were discharged, so that they fell to earth in showers of particles like gravel. Of this first eruption there is little trace now, unless the grits of Straub and Grouse mountains be the remnants, as is probable,‡

* The writer, then a student at the Royal School of Mines, saw this volcanic ash under the microscope after it had been collected from the London atmosphere, which hardly needed solid contributions from such a distant source.

† See Fig. 1 and the corresponding text.

‡ This is the opinion of Whitman Cross. See page 71, *op. cit.*

of the *débris* accumulated at that time. Material resembling this must certainly have covered the surface around the vent, until the larger portion of it was washed away. The steam which, in enormous volumes, accompanies the first outbursts of volcanic action, becomes condensed as soon as it issues into the cold air and forms rain-clouds, the downpouring of which frequently removes the accumulations formed at the initial stage of the volcano. The floods which succeed eruptions are due to the super-saturation of the atmosphere with the water-vapor emitted by the volcano. Such floods are more feared by the dwellers around Vesuvius, for example, than the lava-streams, the destructive effects of which are comparatively restricted. It was the formation of a liquid mud, by the action of heavy rains on the fine material, called "tufa," which buried the city of Herculaneum.

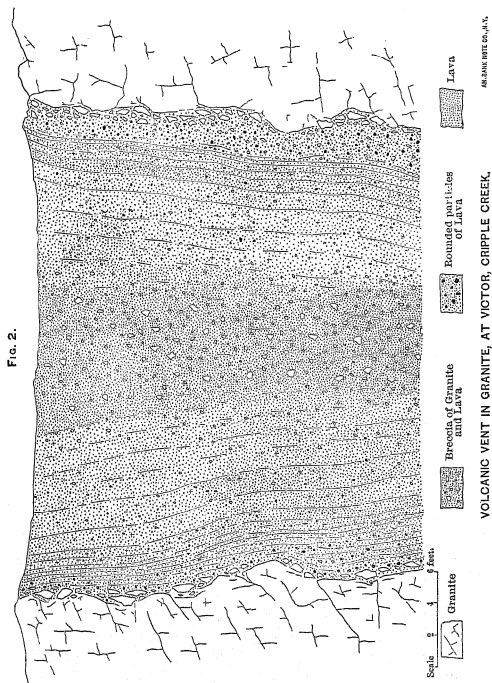
It is unlikely that sufficient data will ever be forthcoming to give an exact presentation of the chief vent of the Cripple Creek volcano, unless one of the millionaires, enriched by the gold he has won from the mines, shall prove as public-spirited as Goethe's friend, and shall undertake the requisite explorations. Yet some very interesting evidence on this point is available. A miniature vent* exists near the town of Victor, and the railroad has cut through it, so as to furnish the section of it shown in Fig. 2. As a hand-specimen may exemplify the structure of a mountain range, so this small vent typifies many of the characteristics of the orifice probably existing in the earlier stages of the Cripple Creek volcano.

This vent occurs in the massive granite of Squaw mountain, about 1700 feet south of the main breccia-formation of Battle mountain. In the railroad-cut, where it is to be seen, it has a width of 35 feet. It is filled with fragments of granite and the gravel derived from the brecciation of granite. The edges are not particularly well-defined, because the face of the enclosing rock is shattered. The most peculiar feature of the section is presented by pellets, nodules and rounded fragments of dark-red scoriaceous lava, which occur all through the material filling the vent. At the edges, rounded inclusions† of this lava can be

* Whitman Cross describes this vent on page 77 of his Cripple Creek report.

† The largest are 1 to 1½ inches in size. On microscopic examination Professor Kemp found it difficult to determine the exact petrographic character of this lava. "It shows only alteration products in some parallel arrangement, but not in sig-

seen in the mass of fragmentary granite; and in the center the lava, by reason of oxidation, forms a red granular matrix, in which large pieces of granite are separately discernible. The



material, especially near the edges, has a laminated structure, parallel to the sides of the vent. These laminations vary in thickness according to the coarseness of the material.

nificant condition." In both of the specimens I sent to him he detected large scales of biotite. Having in view this fact, and the character of the material, it seems most probable that the lava closely resembles the rock of the basaltic dike in which the neighboring Anna Lee ore-chimney was found to occur.

This illustration is of great interest. The vent is in granite, as was the first vent of the volcano. It is now filled with breccia, as, at one time, that was. The shattering of the sides is suggestive of the mode of formation of the breccia, which now fills it. Had this vent been further enlarged, and subsequently penetrated by phonolite, not in fragments, forming a breccia, but in liquid form, solidifying to a compact mass, it would have presented a complete analogy to the Cripple Creek volcano. .

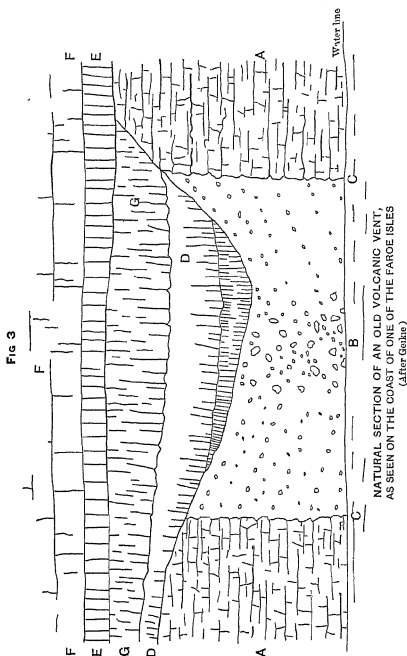
As another example, but from a different locality, of a natural section of a small vent, I would instance that shown in Fig. 3, which represents a drawing recently made by Sir Archibald Geikie,* while traveling among the Faroe Islands, in the North Atlantic ocean. The action of the waves has cut down the face of the cliff, so as to exhibit its structure very clearly. The vent occurs in banded lava (A, A) and has a diameter of about 100 yards. It is filled with agglomerate (B) consisting of compacted *débris*, in which lie large fragments of slaggy lava, the largest being in the center of the former orifice. The filling is arranged in distinct layers toward the sides. The top of the vent is saucer-shaped, and is covered with three successive flows of basalt (D, G, E); of these, the lowest has merely extended over the center of the vent, while the next (D) nearly covers it, and the uppermost (G) lies over the whole of it. Above these there are other layers of basalt (E, F) which completely bury the orifice.

After the first outburst, a change took place in the matter ejected by the Cripple Creek volcano; there began to appear the fragmentary andesite which was destined to be accumulated to such an enormous thickness. It may be that flows of andesitic lava also welled out over the surface at this time. If so, they were subsequently eroded. During the long intervals of quiet separating one period of eruption from another, the lava became cooled, cracked, and then disintegrated by rain and frost, so as to be broken up and carried away by the mountain streams to form a part of the alluvium of the valleys. Thus the superficial flows were removed; but the corresponding bodies of lava which consolidated underground, when the extrusion at the surface had ceased, are now, thanks to that very

* "The Tertiary Basalt-Plateaux of Northwestern Europe" *Quarterly Journal Geological Society*, vol. lii, p. 344

erosion, to be seen as bodies of andesite rock in several parts of the district, notably on the eastern side of Battle mountain and near Legal Tender Hill, above Goldfield.*

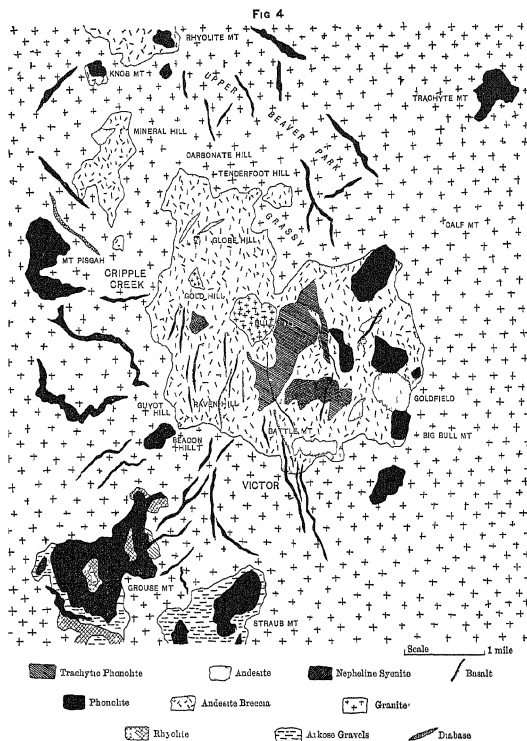
The fragmentary eruption of andesite continued. At this time the volcano must have been a splendid sight, especially by



NATURAL SECTION OF AN OLD VOLCANIC VENT,
AS SEEN ON THE COAST OF ONE OF THE FAROE ISLES
(After Gehe)

night. It was so late in geological time that Pike's Peak was already a giant among its fellows, and towered in lonely grandeur above the lesser hills where the eruption was taking

* As the accompanying geological map (Fig 4) of the district illustrates. This map is a reduced copy of the colored map published by the United States Geological Survey. The ideal section which I have drawn (Fig 5) is taken in an east and west line across the southern part of the area.

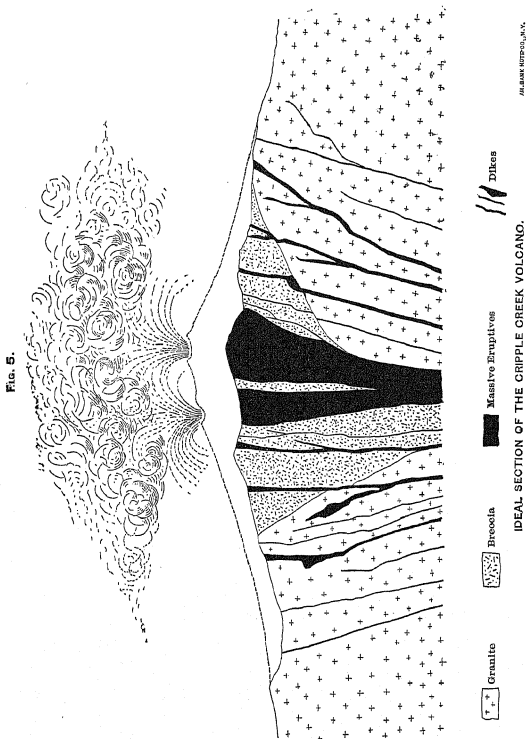


GEOLOGICAL MAP OF THE CRIPPLE CREEK DISTRICT.
(After U S Geological Survey.)

place. The shifting lights of the volcano were reflected by the snow-fields of the peak. Those lights were due to the glow of the incandescent lava in the crater thrown upon the clouds* of

* Professor Judd very aptly likens this effect to that caused when, at night, the engineer of a locomotive pulls open his furnace door and permits the light of the fire to be thrown upon the stream of vapor issuing from the funnel.

watery vapor which hovered overhead. To this appearance* were added lightning-flashes. The steam issuing through the



orifice of a volcano is highly charged with electricity, generated by its upward rush, and the friction of the colliding particles

* The old idea of a volcano was a mountain which spouted fire, ashes and smoke. The "fire" is the reflection referred to above; the "smoke" is vapor; the "ashes" are lava rendered vesicular or pumice-like by the bubbles of steam penetrating fused rock.

of solid matter ejected with the steam contributes further in producing a condition of intense electrical excitement. This is relieved by discharges into the surrounding atmosphere.

The lightning illuminated the surrounding hills and shone around Pike's Peak, the hurtling of the fragments of rock as they met in mid-air and the sound of their fall as they rattled down the slope of the volcano mingled with the muffled roar of escaping steam and the occasional rumbling of the thunder.

There was none to see it. Man was not yet on earth, though the footsteps of his oncoming could almost be heard.^{*} Of animal life no traces have been found in the Cripple Creek formation. Bird and beast fled from the terrible sights and sounds. But remnants of the vegetation of that time have been preserved, and at depths of many hundred feet beneath the surface of to-day the miner has encountered the remains† of trees, resembling pines, which were overwhelmed by the eruption.

At this period similar outbursts were occurring among the neighboring hills, for the Cripple Creek volcano was but a minor incident among the eruptions which, during the Tertiary epoch, spread a vast thickness of breccia and lava over a large portion of southern Colorado. Out of the products of these eruptions were sculptured the serrated peaks of the Uncompaghere, the Cochetopa hills, and the rugged ranges of the San Juan

After the eruption had continued sufficiently long to form a vast accumulation of the fragmentary materials, which in process of time became consolidated into breccia, there came a period of comparative quiet.

* The earliest vestiges of man belong to the close of the Miocene period.

† These are various. In the Jack Pot mine, at 400 feet from the surface, in the Logan at 600 feet, and in the Doctor at 700 feet, there have been found fragments of coal, exhibiting traces of wood-structure. In the Independence, at 500 feet, a stump of a tree was discovered in the very midst of rich ore. In every case the enclosing rock was breccia. The specimen from the Independence is stone, the others are coal. In the former case, the tree-portion must have become buried under conditions free from access of air, and must have been subjected subsequently to the action of siliceous waters, which gradually replaced the fiber of the wood with a mineral precipitate. In the other cases, the tree must have become enclosed within the breccia and subjected to a slow oxidizing action which carbonized the wood, without permitting it to burn freely. Otherwise, it would have been destroyed, leaving only ashes. As it was, it became coal, carrying 60 per cent carbon, and having the other characteristics of a typical lignite.

The Cripple Creek volcano must have formed a conspicuous mountain. This is inferred from the nature of the material ejected. The size and shape of the cones formed by the emissions of a volcano depend upon the condition in which they are emitted. Limpid lavas, like those of the Hawaiian volcanoes, form extremely flat cones. Mauna Loa, for example, has a height of 13,675 feet above the sea, with a base of over 70 miles, the slopes having, according to Dana, an angle of 4° to 6° only. The great volcanic cones of the Andes are made up of a much less liquid lava, and, according to Whymper, have slopes which range from 27° to 37° . Mount Shasta, in California, which is built up of similar rocks, stands, according to Whitney, at an angle ranging from 28° to 32° . A cone such as that formed around the vent of the Cripple Creek volcano, which emitted vast quantities of fragmental material alternating with occasional lava-flows of the more viscid type, would partake of the character of the well-known p \ddot{u} ys or peaks of Auvergne, which dot the surface of that part of south-central France, in shapes resembling a candle-extinguisher. Breccia and lava together make steeper cones than lava or breccia separately; therefore the Cripple Creek volcano, when at its maximum height, must have appeared as a steep mountain.

Projectile discharges were succeeded by tranquil emissions of lava. The bodies of massive andesite in the southeastern part of the district may represent such extrusions. They were marked by an absence of the violence which accompanied the earlier outbursts, due, perhaps, to a diminution in the quantity of escaping steam and a lessening of the pressure upon that which remained. The earlier ejectamenta of a volcano are scoriaceous and vesicular, that is, they have been penetrated and torn by the explosive escape of superheated water-vapor, while the lava characterizing the later stages of activity is compact and homogeneous. The creation of a vent serves as a safety-valve in releasing the tremendous pressure of the steam, due to its sudden expansion when coming into contact with incandescent fused rock. Attendant upon the relief given to that pressure, are all the terrifying phenomena of the first outburst. Subsequently the force of the eruption diminishes. The lava ceases to be violently projected by escaping high-pressure steam. The underground waters near the conduit have become used up.

The rise of the lava underground, followed by its protrusion at the surface, becomes a quiet process, which must be referred to a more deep-seated cause, namely, the local readjustment of the earth's crust, causing the fused rock to ooze out slowly. Many lava streams have a glacier-like movement. They seldom progress more than 3 miles per day, and often require a year to advance a few miles *. Observers have described the flows of lava which follow the first eruption as welling out "with the tranquility of a water-spring,"† as "proceeding in silence,"‡ as "being effected quietly and without noise."§ All this is in vivid contrast to the paroxysmal outburst which marks the first stage of volcanic activity. The difference is to be referred to the relative quantity of steam taking part in the process of eruption.

The period of quiet may have been, and probably was, succeeded by a complete, though temporary, cessation of activity. This interval may have persisted for several hundred years. Geology is lavish of time. The inaction was due to the diminution of pressure consequent on the withdrawal of the lava in the conduit of the volcano. Such a result would be brought about by the shifting of the center of eruption to another place along the line of fissure. The island of Vulcano, in the Lipari group, affords an excellent example of such a change of vent. Among the extinct craters of Auvergne|| in south-central France, similar instances are numerous. (See Fig. 6.) The first conduit of the Cripple Creek volcano became plugged up by material which had failed of ejection. Other minor vents may have been formed on the flanks of the mountain which had been slowly formed by the long continuance of discharges. When, after an interval, a vigorously active condition was resumed, the second eruption, in all probability, took place through a new vent, produced, as the original one had been, by a fissuring of the rock immediately over congested masses of steam due to the water which had accumulated during the interval of inaction.

* Dana

† Scrope.

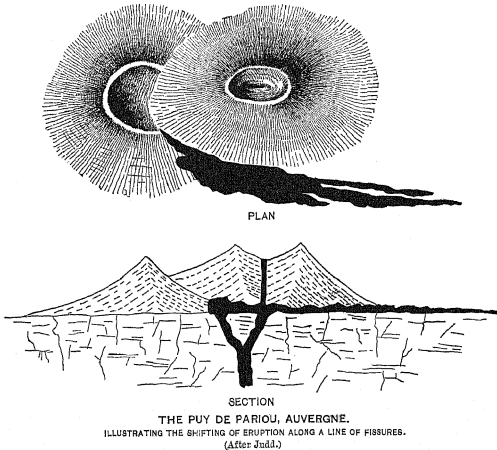
‡ Fouqué

§ *Ibid*

|| The writer cannot claim to have any special knowledge of volcanoes, but he is familiar with the volcanic region of Auvergne, in south-central France, has seen Vesuvius, and has traveled in the volcanic parts of New Zealand, and also in Oahu, one of the Hawaiian Islands

There is evidence indicating that the Cripple Creek volcano had several vents. One existed near the present site of the Hull City placer; another must have been situated near Anaconda. The original position of the orifice of an extinct volcano can be inferred from the composition of the rocks. The lava which cools rapidly in the open air assumes the character of a glassy substance,* containing only a few embryonic

FIG. 6.



crystals, but that which cools slowly underground, and while still subjected to great pressure, is developed into completely crystalline rock. Experiments with smelter-slugs, and a microscopic examination of the resulting material, have confirmed this proposition. In this way the lava streams which have issued from the vent are distinguishable from the material

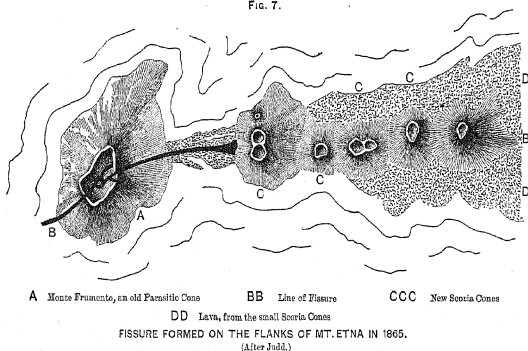
* On June 3, 1840, a stream of lava from Kilauea reached the sea, after having flowed over the island of Hawaii for a distance of 11 miles. "The burning lava, on meeting the waters, was shivered like melted glass into millions of particles, which were thrown up in clouds that darkened the sky and fell like a storm of hail over the surrounding country."—DANA, *Characteristics of Volcanoes*, p. 63.

which has solidified in the throat of the volcano. The nepheline-syenite near the Lillie and Vindicator mines is the granular equivalent of the phonolite which occurs so plentifully all over the district. The phonolite and the syenite have a similar chemical composition, but their texture is very different. This is due to the fact that in the former a crystalline structure has not been fully developed, the ground-mass or matrix, as seen under the microscope, being made up of crystallites, minute, hair-like bodies without the properties of, but with the tendency to become, crystals. This indicates that the rock cooled too rapidly to permit of proper crystalline growth. The nepheline-syenite, on the contrary, is made up entirely of developed minerals, no part of the original ground-mass having failed of arrival at true crystalline maturity, so that even the slight excess of quartz, though uncombined, presents a crystalline structure. This indicates that the rock cooled very slowly, giving ample time for the full play of the forces which produce crystallization. It is to be inferred that the nepheline-syenite fills an old vent, or is close to it. The same inference is drawn from the patch of syenite-porphry between Gold hill and Squaw gulch. Further evidence suggestive of the former existence of a vent thereabouts is afforded by the steepness of the plane of contact between the granite and breccia on the adjoining Guyot hill. The dissection of extinct volcanoes in other parts of the world, a dissection brought about by natural erosion, which has cut valleys right into the flanks of ancient eruptive centers, furnishes numerous examples confirming such deductions as have just been made with reference to the vents of the Cripple Creek volcano. Even in Great Britain, which has not known volcanic disturbances during the time covered by the brief record of human life, there are abundant proofs concerning the shifting of vents and the resulting relations between perfected and undeveloped rock-types.

The occurrence of several vents would not be unusual. Volcanoes are not mere bores through which eruptive discharges take place. Where one single vent survives, it may be considered to represent the centralization of energy due to the choking-up of many other openings along the line of fissure formed at the time of the first manifestation of activity. This is well illustrated in the accompanying sketch of Mount Etna,

as it appeared in 1865. (See Fig. 7.) The expansive force of the steam, to which the violence of the initial stages of volcanic action is due, tends to radiate from the central point of energy so as to form cracks, the character and extent of which will vary according to the structure of the rocks through which the shocks are propagated. At certain points along these cracks, or at the crossing of two of them, openings are formed, permitting eruptive discharge. Those openings which are immediately above the points of greatest pressure, will survive longest; the others become plugged up with the material they are unable to eject. One vent usually remains as the center of

FIG. 7.



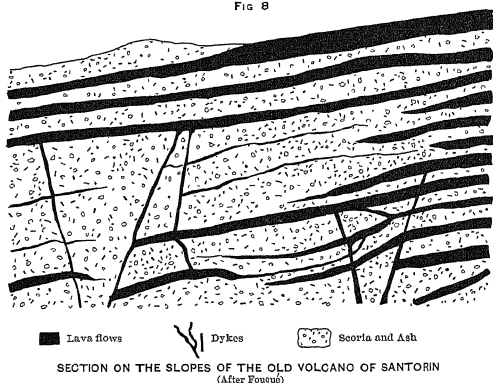
energy. The others become extinct, until an increase of eruptive activity finds a single conduit insufficient, and thus necessitates the obtaining of relief at other points. Lava-flows do not necessarily take place at the central vent. Many of the largest flows known to have occurred among the Hawaiian volcanoes, for example, have emanated, not from the crater at the top of the mountain, but far down upon its flank. In certain instances, as at Kilauea,* the larger number of discharges have been subterranean.

The subterranean discharges of lava are of peculiar interest

* Dana. That of July, 1840, started at a point 16 miles distant from the crater.

to the miner, because they are among the factors which he has found by experience to influence the distribution of the ores which he seeks. They are to be seen both in natural sections, afforded by ravines, and in those other sections of the rocks which are presented underground in the mines. The accompanying drawing,* after Fouqué (see Fig. 8), of a natural section seen on the slope of the old volcano of Santorin, will be suggestive. These intrusions take a variety of forms. Such as seek out the lines of weakness presented by the bedding-planes of sedimentary rocks, or the lines of successive deposi-

FIG 8

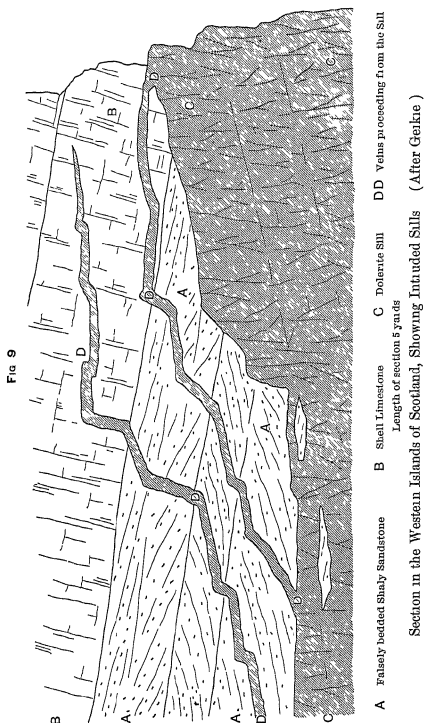


tion of fragmentary volcanics, form sheets. In England, such an intrusive sheet is termed a "sill." An instance is illustrated in the accompanying section, obtained in the western islands of Scotland by Sir Archibald Geikie.† (See Fig. 9.) The intrusive masses of porphyry (quartz-felsite) which, at Leadville, penetrate the sedimentaries, afford an example which is of peculiar interest on account of the remarkable ore-deposits found at the contact of the porphyry with the Carboniferous limestone.

* From *Santorin et ses Éruptions*.

† "The Tertiary Basalt-Plateaux of Northwestern Europe"—*Quarterly Journal Geol. Soc.*, vol. 11, p. 377

Those subterranean flows of lava which do not find a ready passage, either in a lateral or a vertical direction, tend, when thus impeded, to congest locally, so as to form huge under-



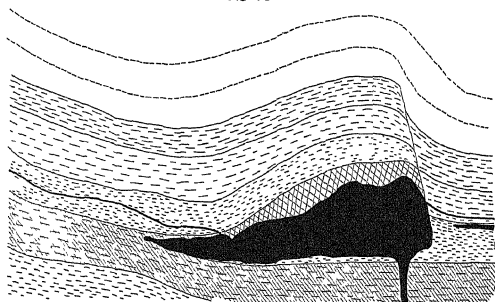
ground blisters which are sometimes large enough to arch the overlying strata into dome-shaped hills. Such "laccolites,"* as they are termed, were first recognized as a type by G. K.

* From the Greek *laklos*, cistern, and *lithos*, stone Laccolith would be a better
rm

Gilbert * Since then, Whitman Cross† has described similar occurrences in southwestern Colorado. The accompanying drawing (Fig 10) represents his ideal section of one of these enormous cores of what was once fused rock. In this particular section, of Mount Marcellina, it is evident that the porphyrite has arched the overlying coal-bearing strata to the point of rupture, a line of fracture being indicated to the right of the laccolite.

Such intrusive masses as have been described are encountered by the miner with much less frequency than the dikes, which are approximately vertical sheets of igneous rock, evi-

FIG 10



THE LACCOLITE OF MT MARCELLINA
(After W Cross)

AM. BARK. NOTE CO. N. Y.

dently filling cracks which usually extend to a depth greater than any existing mine-workings. In underground explorations we sometimes come across dikes which have failed to reach the surface; and, more rarely, it has been found that the lower end of one of these vein-like bodies merges into the very heart of a large mass of similar rock. It is inferred that every dike emanates from some central core, because a purely local origin is not conceivable, the conditions which induce liquefaction and those which compel the upthrust of the fused rock are alike referable to factors created by the forces at work

* "Report on the Geology of the Henry Mountains," 1877

† "The Laccolitic Mountain Groups of Colorado, Utah and Arizona," 14th Annual Report U. S. Geol. Survey, Part II, pp 165-241

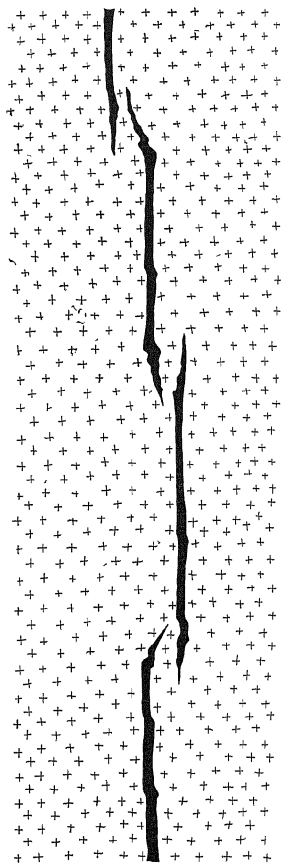
within large masses of rock. The water coming up through a crack in the ice is referred to the body of it beneath that ice. The fused rock rises in the fractures caused by earth-movements much as the water fills the cracks in the ice; that is, no gaping crevasse is necessarily formed, but the lava rises and occupies the fracture as it is formed, it follows it, it does not make it, although the movement which makes the crack and the pressure which squeezes the lava into it may both be traceable, far back, to a common cause.

The behavior of dikes often affords striking evidence of their adaptability to the structure of the rocks they traverse. They seek out lines of least resistance, and thus frequently make evident structural features which otherwise would have been merely latent. The accompanying drawing (Fig. 11) illustrates this. It represents a flat surface of granite (in West Australia) traversed by a dike of dolerite, which has evidently utilized for its passage the lines of fracture produced along a shear-zone in the granite. The very low conductivity of lavas (as of smelter-slag) may explain their ability to pass through rock-fractures for great distances. The edges of a dike would cool instantly, but in so doing would afford a protection to the central portion, the liquidity of which would thus tend to be maintained.

The bulk of the material thrown up by the Cripple Creek volcano was fragmentary, and became the great mass of breccia now constituting the leading geological feature of the district. The earliest lavas extruded were of medium fusibility namely, andesite, and then phonolite. On reaching the surface, they formed streams, the exterior of which became promptly chilled to a black-looking slag, to which escaping steam gave a cindery structure. The lava rolled down the slope of the volcano with the utmost slowness, making clinking sounds such as are heard when the workmen empty the slag-pots over the dump of a smelter. Such lava-streams weather very easily; their exterior, by the contraction of the surface due to cooling, becomes porous, and water penetrates into the mass of them, disintegrating them so that they are readily carried away by the rains of spring.

The last extrusions of the Cripple Creek volcano were of basalt. These were more limpid, and must have formed

FIG. 11.



■ Dike

+ Granite

streams which traveled much farther than the less fusible phonolite and andesite. The basalt, judging from the behavior of similar lava-flows actually observed in the Hawaiian Islands and elsewhere, would progress rapidly down the slopes of the mountain and overwhelm the forests which, probably, clothed the lower portions of the Cripple Creek volcano, setting them on fire and adding greatly to the aspects of destruction presented by the scene. Upon cooling, these basaltic flows would be cleft asunder by symmetrical series of cracks forming prismatic columns grouped like the pillars of a Gothic cathedral. But where they were not protected by a later covering of rock, the ruthless hand of decay attacked them also, the frost of many thousand years shivered the straight columns; and the freshets of spring swept the remnants into the torrents which fed the Arkansas river.

The successive periods of activity in the life of the Cripple Creek volcano are marked by the sequence of lavas extruded. This sequence is indicated by structural relations, the older extrusions being penetrated by the younger. But this is not all. The crystalline structure and the chemical composition of the rocks resulting from the cooling and consolidating of the successive lavas exhibit differences which have been found to be closely analogous to those presented by similar successions of rock at other volcanic centers, both in the United States and in Europe. The earliest lava extruded by the Cripple Creek volcano was andesite. Then came the phonolite, and, lastly, the basalt. These three rocks represent types which vary in their chemical composition and in their consequent fusibility. Basalt fuses at about 2250° F.; certain varieties fuse at about 2000° F. What is usually termed a "white heat" is equivalent to a temperature of 2100° F*. The least fusible rocks are of the granite and trachyte class; they fuse with difficulty at about 2700° F. To the intermediate type belong the andesites, which fuse at about 2520° F.† The relative fusibility of these rocks is dependent upon the fusibility of their chief constituent, feld-

* According to the latest determinations by Henry M. Howe. According to Pouillet's experiments, gold melts at 2192° and silver at 1832° F. See *Eng. and Min. Journal*, Jan 20, 1900, p 75.

† These are the temperatures derived from the experiments of Carl Baisus. See Dana's *Manual of Geology*, 4th edit., p 273, 1895.

spar, the variety in the basalts being labradorite, the most fusible of the feldspars. Moreover, in basalt there is present a good deal of augite, a still more fusible mineral, and a large percentage of iron which, as in smelter-slugs, contributes directly to fusibility. The trachytes are largely made up of orthoclase, the least fusible of the feldspars. The andesites are intermediate in composition and of medium fusibility, their characteristic feldspar being oligoclase.

This fusibility used to be expressed in terms of "acid" and "basic character," the rocks high in silica and low in iron being at one extreme, and those low in silica and high in iron at the other.* But Dana has pointed out that this does not express it correctly, fusibility being dependent not so much on the percentage of silica as upon the amount of alkali, namely, potash and soda.† Thus the rocks rich in alkaline feldspars are the most fusible. Free quartz exists in most rocks; and the percentage of it, which is far from uniform among the members of any particular type, increases the acid character of the rock, so that it becomes a secondary factor in determining fusibility. Similarly iron occurs as an oxide (magnetite) in all rocks, to an insignificant degree in the granites, but in the basalts and gabbros freely, so as to form an important ingredient, giving them their dark coloring. This large percentage of iron contributes to easy fusibility; indeed, certain basalts are known to become so limpid that they can be taken up in a spoon attached to the end of a cane.‡

This question of fusibility would be of slight importance were it not for one interesting fact, namely: it has been observed in several volcanic regions that lava of intermediate composition, such as andesite, is succeeded by those of the extreme types, namely, the very alkaline or comparatively non-alkaline rocks, such as basalt and rhyolite, respectively. This was the case at the Cripple Creek volcano. It has been inferred from these facts that in the earlier stages of volcanic activity the lavas are mingled together underground, and that during the period of eruption the heavier portion separates

* Dana, *Manual of Mineralogy and Petrography*, p. 436

† Dana, *Characteristics of Volcanoes*, p. 146.

‡ This was actually done in the case of the basaltic lava of Kilauea, in Hawaii.
Coan *American Journal of Science*

from the lighter, causing two diverse products to be separately emitted

Eventually (it may have been several thousand years after the first manifestation of activity) the volcanic energies became wearied, and lava ceased to appear at the surface. The readjustment of the earth's crust, at this particular locality, had been accomplished, and a condition of equilibrium supervened. The lava sank beneath the level of the crater, and, on cooling, plugged up the conduit, as was the case, for instance, at the Kammerbuhl *. The sinking of the lava may have gone further, so that the withdrawal from the upper part of the mountain, formed by the ejections of the volcano, may have caused extensive subsidence and created deep fissures. Such was the case at Kilauea in 1832 and 1840.† Those who are engaged in mining at Cripple Creek are aware of the existence of numerous large cavities underground, particularly in the southern part of Bull hill and the northwestern portion of Battle mountain. In the Logan mine the orifice of a very large cavity was recently encountered while sinking the shaft.‡ The sudden flows of water which have embarrassed some of the mines are due to the unexpected drainage of such openings. It is worthy of note that these especially characterize the trachyte-phonolite and those rock-masses which represent the lavas extruded last.

After the volcanic energies had declined, there followed a long period of smothered activity, evidenced by geysers and hot springs. Steam continued to escape, but gently. There was none of the violence of the earlier period. Heated water accompanied the steam, instead of fused rock. The hot lava still existing at greater depth served to give expansive force to the surface waters which found their way, by seepage, through the overlying deposits of volcanic material. The steam and hot water now emitted, at some spots quietly as a thermal spring and elsewhere intermittently as a geyser,§ probably carried a

* Judd's *Volcanoes*, p 114. See also *ante*, pp 371, 372

† Dana's *Characteristics of Volcanoes*, p 124

‡ The miners heard the inrush of air caused when they tapped the cavity and promptly left their work, to go to the surface. It is probable that the pumping operations of the neighboring Portland mine had drained the water, which at one time had filled the cavity, leaving it void.

§ Geyser is an Icelandic word, and means "gusher." A thermal spring which spouts or gushes out above the surface is a geyser

good deal of mineral matter in solution. A wonderful work is accomplished in this quiet way, because such activities extend over enormous periods of time. Professor Judd has shown that the hot spring at Bath (England), although an apparently unimportant geological agent, brings daily to the surface 180,000 gallons of water at a constant temperature of 120° F. This spring was doing its duty at the time of the Roman invasion of England, and it is estimated that since that time it has brought up, in solution, enough material to form a good sized volcanic cone *

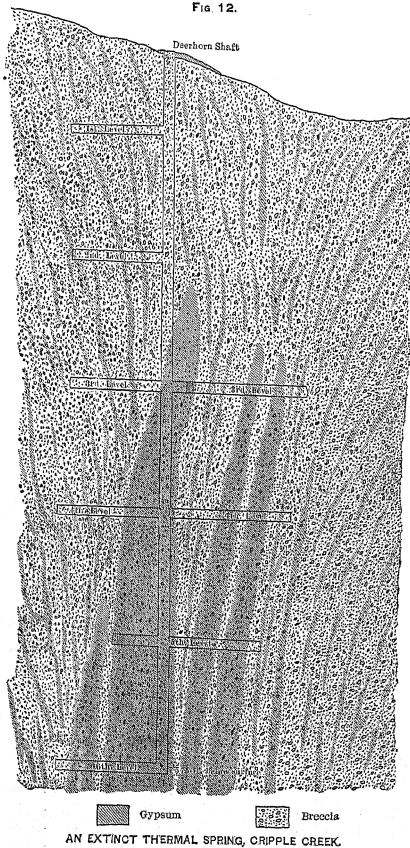
The Cripple Creek district exhibits abundant evidence of hydrothermal action. This is particularly the case in the northwestern part of the mining area. The breccia of the upper parts of Globe and Ironclad hills, penetrated by the workings of the Deerhorn, Summit, South Park, Plymouth Rock and other mines, is much decomposed, and has a loose, crumbly character. It is seamed to an unusual degree with irregular fractures, lined with secondary minerals, among which crystalline gypsum and amorphous kaolin are the most common. In the Deerhorn shaft there is evidence of a more definite kind. At a depth of 240 feet the shaft cuts into a mass of gypsum, and from that point to the bottom, 575 feet below the surface, it has been sunk in the midst of what appears to be a series of extinct thermal springs. The accompanying drawing, Fig. 12, will illustrate the occurrence

The workings are very extensive in a direction at right-angles to the plane of the section followed by the illustration, and connect with the adjoining mines. Breccia and tuff compose the prevailing rock †. No distinct dikes are visible near the Deerhorn shaft; it is probable, judging from the composition of the breccia at several points, that several intrusions do exist, but that they have been so shattered in place as to be scarcely distinguishable from the original breccia which surrounds them. At the third level, and at the succeeding levels, there are three distinct narrow-pointed cones of com-

* Page 219 of *Volcanoes*

† The breccia was found by Professor Kemp to contain undoubted fragments of kaolinized granite, decomposed orthoclase being easily recognizable. The breccia of Cripple Creek, although fragmentary andesite predominates, everywhere exhibits a scattering of granite particles, which in places become so numerous as to give it a truly granitic character.

FIG. 12.



fact white gypsum which, at 15 to 25 feet from their apex, graduate into chimney-like masses of breccia cemented by

crystalline gypsum. At the sixth level there is a fourth of these occurrences. Others, which do not happen to have been intercepted by the workings of the mine, may exist in the vicinity.

Iron pyrites is found in the gypsum; it occurs as a scattering of coarse crystals in the upper portion, and finely disseminated lower down. The white gypsum carries patches which are stained pink by fluorite. The surrounding breccia is everywhere traversed by color-bands due to layers of gypsum, manganese oxides, and iron ocher. Scattered through the vicinity, but parallel to the group of columns above described, there are patches, as well as seams, of fluorite sand, consisting of particles of crystalline silica stained purple by admixture with fluor-spar. The upper levels also show bands of a white unctuous clay, named "Chinese talc" by the miners. This is pure kaolin,* derived from the decomposition of the feldspar in the andesite fragments composing the bulk of the breccia. The latter is in a crumbly condition, its character being suggested by the fact that in driving the levels only a pick is needed, the ground requiring no blasting. Beyond the central portion, which has structural lines sympathetic to the arrangement of the columns of gypsum, the breccia is still stained and disintegrated for a great distance, and in places exhibits suggestions of the neighborhood of other thermal conduits.

There can be no doubt as to the nature of these masses of gypsum. Thermal springs which have become extinguished are marked by just such accumulations of lime, although the carbonate is, under such circumstances, more common than the sulphate.† The flows of hot water encountered in the deep

* The following is Dr. Hillebrand's analysis, made by him for Prof. Penrose. See page 128 of the Report on "The Geology and Mining Industries of the Cripple Creek District," *U. S. Geological Survey, 16th Ann. Rep., Part II*

Silica,	45.08
Alumina,	31.83
Ferric oxide,	95
Lime,	1.76
Magnesia, . . . . .	.59
Potash, . . . . .	.14
Water,	19.96

100.31

† Siliceous deposits characterize geysers.

workings of the Comstock carried a notable percentage of gypsum. Last April, while examining certain copper-mines near Hawthorne, in Nevada, the writer came across a group of similar vents, marking the site of former thermal springs. The conduits, in this case, occurred in lime-shales, and were still open to a considerable depth, as was proved by dropping stones into them. They were surrounded by a compact chimney of carbonate of lime, which had also overspread the enclosing rock.

Recurring to the conditions observed in the Deerhorn shaft, it would seem that the rising hot waters, in their approach to the surface, were unable to maintain a defined channel through the breccia higher than the level marked by the tops of the cones of gypsum. This might be caused, first, by the fact that the vapors ascending above the subterranean springs disintegrated the breccia so as to destroy its cohesion, and changed it from a compact rock to loose material. The most potent factor, however, was probably the diffusion of the ascending waters into the drainage of the surface, the effect of which would be encountered at this horizon. The condition of the breccia and the wide area which has undergone disintegration favor this view.

It is in accord with facts observed in other regions that the vents which permitted the emission of lava-flows should be in one part of the volcanic area (in this case the southern portion) while the escape of hot waters which marked the time when the volcanic energies were waning should have occurred in another part, in this case the northern and northeastern. The lava had healed lines of weakness, it had cemented the fractures produced by the earlier paroxysmal efforts of the volcano, and therefore the thermal waters found a better chance of exit elsewhere. With the hot waters which found their way to the surface during the closing period of the volcanic cycle there were emanations of gas. Sulphuretted hydrogen was probably emitted, sulphurous acid gas, and, in all likelihood, carbonic acid gas also, although not all of these were to be found at one place or at one time. The volcano had now reached the "solfatara" stage.* These acid gases played an important part in

* "Solfatara" is from the Italian "solfo," meaning sulphur. It is a name given to one of the small volcanoes, near Naples, which is in a condition such as marks the dying out of volcanic activity.

altering the volcanic rocks, and were, possibly, a factor in the process of ore-deposition which was beginning. The vapor of hydrofluoric acid was also among the agencies at work. This is inferred from the large amount of fluorite, the fluoride of calcium, which occurs all over the district, and more especially in the gold-bearing lodes. Fluorite is not common in volcanic regions, although it is found in the lava of Vesuvius. The action of hydrofluoric acid on feldspars containing lime would form fluorite. It would also convert gypsum in a similar way. Fouqué has shown that the action of hydrofluoric acid in the liquid state is to decompose, first, uncrystalline silicates or glasses, then feldspar and other acid silicates, then quartz, and lastly, basic silicates. Whether the vapor of hydrofluoric acid would act in the same way is uncertain, although it is possible that in this case quartz might be attacked in preference to the feldspar. This is a matter of interest, because in examining specimens of granite which have been converted into ore (by the addition of gold-bearing tellurides) it is observable that the original quartz of the granite has been attacked while the orthoclase remains comparatively fresh.

This last stage of the Cripple Creek volcano is of great importance to the mining geology of the region. It extended over an enormous period, coinciding, roughly speaking, with that which has elapsed since the time to which is ascribed the first evidence of the existence of the human genus, and it afforded, to an unusual degree, those particular conditions which are considered to favor the deposition of precious ores. During this time, also, the breccia, with its finer portions, the tuff, became solidified. The pressure of the overlying masses of lava which at one time covered it, and the chemical solutions, which deposited fresh crystalline substances in the interspaces, converted the scoriaceous material into a compact mass, which eventually became solid rock as we now see it. The cooling of the intrusive bodies of lava caused them to contract, and thus developed lines of weakness along which the energies of the volcanic center developed fractures permitting the subsequent prolonged circulation of underground waters. The readjustment of this particular portion of the earth's exterior, which followed the cessation of volcanic eruptions, and the partial settling of the entire mass forming the Cripple Creek

volcano, must have formed an extensive system of ruptures, which afforded lines of maximum porosity along which the gold-bearing solutions found passage-ways. Thus the hot waters which are supposed to dissolve out the metals from the deep-seated rocks were permitted to ascend toward the surface, where the release from pressure and the lowering of temperature forced them to precipitate their contents.

The activity of the geysers ceased; the warmth of the water bubbling from the springs gradually diminished; and at length the last vestige of the volcanic fires passed away. The mountain became as cold as the snow which mantled it each winter, and as still as the darkness enshrouding it nightly.

Geological Relations of the Iron-Ores in the Cartersville District, Georgia.

BY C WILLARD HAYES, U S. GEOLOGICAL SURVEY *

(Washington Meeting, February, 1900)

ONE of the most productive iron-ore districts of the southern Appalachians lies in the vicinity of Cartersville, in northwestern Georgia, where the ore-deposits are so directly related to the stratigraphic and structural features of the region that a description of its geology possesses economic as well as scientific interest.

Stratigraphy.—The area shown on the accompanying map, Fig. 1, occupies the southeastern portion of Bartow county, Georgia. It is about equally divided between the older crystalline and metamorphic rocks which occupy the Piedmont plateau and Appalachian mountains on the east, and the Paleozoic formations which occupy the Appalachian valley on the west. The line separating these two groups of formations enters the mapped area near the northeastern corner, and, pursuing a somewhat irregular diagonal course, leaves it, as shown on the map, near the southwestern corner. This line marks

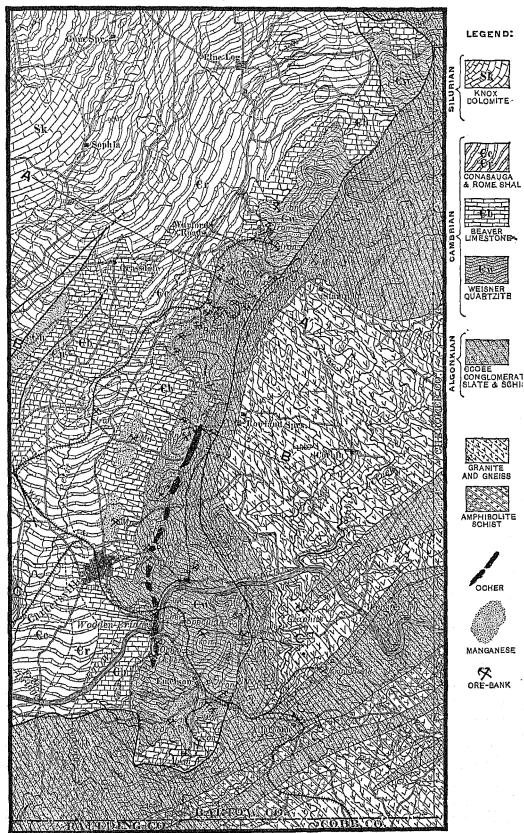
* Presented by permission of the Director of the U S. Geological Survey

the position of the Cartersville fault, the most important structural feature of the region, and one which will be more fully described in a later part of this paper.

The formations of the valley-belt, to the west of the Cartersville fault, are, in ascending order, as may be seen in Fig. 1, and in the sections given in Fig 2, the Weisner quartzite, the Beaver limestone, the Rome and Conasauga shale, and the Knox dolomite. All, except the latter, belong to the middle and lower Cambrian; and the lower portion of the Knox dolomite should probably also be classed with the Cambrian. The principal outcrop of the Weisner quartzite forms a nearly continuous band, 15 miles in length, and generally from 1 to 3 miles in width, which occupies the central portion of the area mapped. The formation is in contact on the east with the Cartersville fault, and its base is nowhere shown. It consists chiefly of fine-grained vitreous quartzite, although it also contains some beds of fine conglomerate, and, probably, considerable beds of siliceous shales. The latter, however, are usually concealed by the abundant *débris* from the quartzite beds, which tend to break up into angular fragments when exposed to atmospheric conditions. Two subordinate outcrops of the quartzite occur near the western margin of the mapped area, being brought to the surface by small faults. The thickness of the formation is probably 2000 or 3000 feet, and may be considerably more, but it cannot be determined, because of the intense folding which its beds have undergone, and the absence of satisfactory exposures.

West of the quartzite is a narrow belt of deep red soil, usually forming a level valley. This is underlain by the Beaver limestone, a formation which rarely appears at the surface, its outcrops being almost everywhere covered with a deep mantle of red clay, in which occasional masses of vesicular chert are embedded, along with much angular quartzite, derived from the adjacent quartzite ridges. A few natural exposures of this formation which have been observed, together with the results of drilling, indicate that it is a grey crystalline dolomitic limestone, becoming shaly in places, and containing occasional masses of chert. It is much more readily soluble than the purer blue limestones; and its impurities form an abundant residual mantle. In addition to the main belt which

Fig. 1.



SCALE 1 1/2 0 1 2 3 4 5 MILES
1 1/2 0 1 2 3 4 5 KILOMETERS

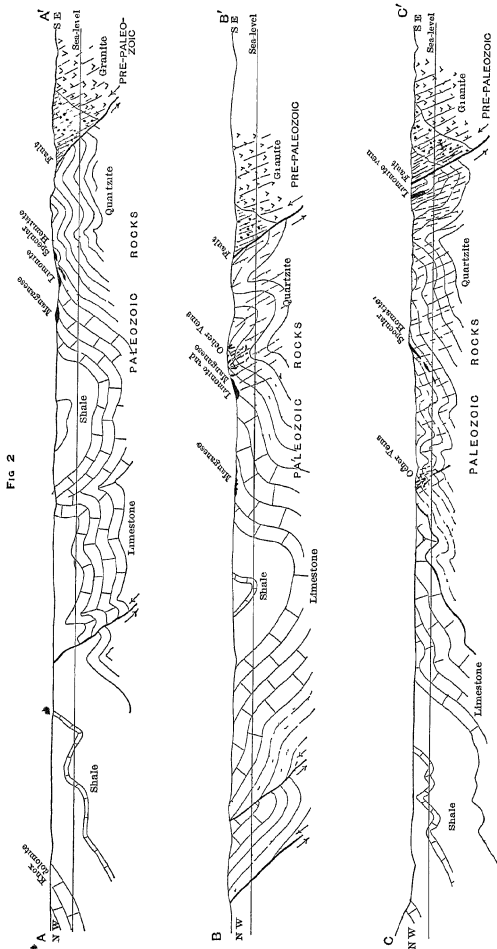
Contour interval 100 ft. datum, mean sea-level

GEOLOGICAL MAP OF THE CARTERSVILLE DISTRICT, GEORGIA.

it forms along the western base of the quartzite ridges, it underlies a broad level valley near the western margin of the mapped area, extending southward from Grassdale to the line of the Atlantic and Western railroad. The thickness of the Beaver limestone has not been accurately determined; but it is probably between 800 and 1200 feet. With these two formations, the Weisner quartzite and the Beaver limestone, a majority of the ore-deposits in this region are associated.

Overlying the Beaver limestone is a very great thickness of shales, constituting the Rome and Conasauga formations; and above the shales is the Knox dolomite. The latter is a massive formation from 3000 to 5000 feet in thickness, composed of grey crystalline dolomite, with an abundance of chert. In adjacent regions, it is intimately associated with extensive deposits of iron-ore; but it is unimportant in the present connection.

The rocks on the opposite side of the Cartersville fault, occupying the eastern half of the mapped area, present considerable variety in composition and age. A large area, extending from Stamp creek southward, across Etowah river, to the Atlantic and Western railroad, is occupied by the Corbin granite, which is, for the most part, a massive coarse-grained rock, containing large porphyritic crystals of feldspar (microcline) in a ground-mass of plagioclase feldspar, muscovite-mica, and blue quartz. Some portions of the rock have undergone considerable alteration, being converted into an augen-gneiss. This area of Corbin granite at one time probably formed an island, since it is surrounded, in part at least, by rocks derived from its waste. These are feldspathic conglomerates, in which the blue quartz and the porphyritic crystals of microcline, which characterize the granite, can be readily distinguished. In some places the transition from granite to conglomerate is so gradual that it is difficult to determine the exact boundary between the two formations. The development of the gneissoid structure in the granite evidently took place after it was deeply buried by sediments; for the alteration of the latter is even more marked than that of the granite itself. Wherever the granite is not bordered by coarse conglomerate or quartzite, it is in contact with black graphitic slates, which generally overlie the coarser sediments.



SECTIONS ON LINES INDICATED IN FIG 1, SHOWING GEOLOGIC STRUCTURE OF THE CARTERSVILLE DISTRICT.
Scale, horizontal and vertical 1 in. 5000 ft

These conglomerates and slates associated with the granite belong to the Ocoee series, which reaches its greatest development in eastern Tennessee and western North Carolina. No fossils have yet been found in the rocks of this series, although many of them are only slightly altered, and fossils would undoubtedly have remained if they had ever been present in the rocks. They comprise limestones and slates similar to portions of the adjacent valley-formations; but the latter are always found to contain more or less abundant traces of life. In the absence of fossil evidence, and because the rocks of this series have every appearance of extreme age, they have been correlated with the Algonkian.

The rocks of the Ocoee series generally show an increasing degree of metamorphism toward the southeast; and within a few miles of this region they pass into schists and gneisses, the original form of which, whether igneous or sedimentary, cannot be readily determined. This increased metamorphism toward the southeast is due in part to the greater compression which that region has suffered, and in part to the presence of considerable bodies of various igneous rocks which have been intruded into the sedimentary beds. These intrusive rocks present considerable variety in composition, varying from extremely basic diabase to acid granites. The most common variety is a diorite, which was among the earlier intrusions, and has been subsequently converted for the most part into amphibolite-schist. Two belts of this basic schist are shown passing across the southeastern corner of the mapped area. The extreme southeastern corner of the mapped area is occupied by the Acworth gneiss, which, like the Corbin granite, is probably Archean in age, and formed the foundation on which the oldest sediments of the region were deposited.

Structure.—In common with other portions of the southern Appalachian region, the Cartersville district has been subjected to intense compression in a northwest-southeast direction. From evidence obtained in adjoining regions, it appears probable that this compression, and the subsequent folding, began in early Paleozoic time, and continued at intervals up to its culmination at the close of the Carboniferous. It resulted in the formation of folds and faults in the valley-rocks, and in the development of a slaty cleavage or schistose structure in the

older rocks to the east, while the latter were thrust upward and westward relatively to the former, producing the great Cartersville fault. The region west of the mapped area is occupied by a broad, gentle syncline of Knox dolomite. This massive formation appears to have resisted folding, and to have transmitted the thrust in such a manner that, while its own beds retained very nearly their original horizontal position, the beds coming to the surface in narrow belts on either side were intensely folded. Thus the shales which occupy the western portion of the mapped area are highly contorted, and are doubtless intersected by numerous small faults. Also, considerable slaty cleavage has been developed in them. The Weisner quartzite likewise resisted folding to some extent, although its beds were thrown into the form of an anticline with numerous irregular minor folds. The irregularity of the anticline is shown by the character of the line which marks its contact with the overlying limestones to the west. In addition to the folding which the quartzite has undergone, it is doubtless intersected by numerous faults, the evidence of which is seen in its crushed and brecciated condition at many points. Owing to the character of the outcrops, however, these faults generally cannot be located or traced.

The folding referred to brought about certain mechanical and chemical conditions favorable for the deposition of mineral deposits, and hence has an important bearing on the economic geology of the district. It is frequently observed that the originally compact vitreous quartzite is converted into a rock somewhat resembling jasper. Chert from the overlying limestone, under similar conditions, is altered in the same manner; and it is often impossible to distinguish between the final products of the alteration of rocks originally wholly unlike. Portions of the quartzite have been converted into a spongy rock containing innumerable fine cavities lined with small quartz crystals and stained with yellow ocher. This form of alteration is probably due to the circulation through the rock of thermal waters, by which the quartz was taken into solution and in part redeposited, along with more or less iron oxide.

The line marking the Cartersville fault departs in this region from its rather regular course across northwestern Georgia, making a distinct embayment to the eastward in passing

around the belt of lower Cambrian quartzite and limestone. On either side of this region the fault brings the soft slates of the Ocoee series in contact with Cambrian shales of a similar character. The actual plane of contact between the formations on opposite sides has been observed at many points. The older rocks above always have a well-developed slaty or schistose structure, and are but little more altered immediately at the fault than elsewhere. The underlying rocks, on the other hand, are much more intensely folded and brecciated immediately at the fault than a few feet distant. The fault-plane itself is usually marked by a bed of breccia, a few inches or feet in thickness, and made up of the comminuted fragments of the formations on either side. This fault-plane dips to the eastward, usually at angles varying between 5° and 20° , and is parallel, in a general way, with the cleavage and bedding of the rocks on either side.

The Weisner quartzite varies greatly in thickness within a short distance. It has the appearance of a delta-formation rather than an evenly distributed littoral or marine deposit. North and south of its present outcrops in this region, it probably becomes very much thinner; and its local thickening has doubtless influenced the structure in this region. Another factor which has been important in producing this peculiar structure is the presence of the great mass of granite to the east of the fault. This is the only point at which massive rocks of this character approach so near to the fault-line. They are usually separated from the western margin of the metamorphic rocks by a belt, several miles in width, of readily-yielding slates and schists. It is evident that the conditions for the formation of a thrust-fault of great lateral extent are much more favorable in bedded sedimentary rocks than in the massive igneous rocks, such as the Corbin granite. The latter appears to have acted like an immovable buttress against which the rocks from the west were thrust. It will readily be understood that, on account of these massive quartzites on the west, and the still more massive igneous rocks on the east, this portion of the Cartersville fault differs materially from that to the north and south; and further, the reasons will be seen for the very considerable alteration, both physical and chemical, in the valley-rocks adjacent to the fault.

Classification of the Southern Appalachian Iron-Ores.—The iron-ores of the Southern Appalachian region fall naturally into five distinct groups, as follows (1) magnetite, (2) specular hematite, (3) red hematite or fossil-ore, (4) carbonate or black-band ore, and (5) brown hematite or limonite. Only two of these groups occur in the Cartersville district, namely, the specular hematite and the brown hematite or limonite, and of these, the latter is much the more important.

Specular Hematite—This variety of ore occurs at two points in the district in sufficient abundance to be mined with profit. One is about 2 miles southeast of Warford, and the other between Emerson and the Etowah river. The ore occurs at both localities as a band in the quartzite, and both the ore and the inclosing quartzite have a strongly developed schistose structure. The ore passes into the quartzite by a gradual transition, and only the richest parts of the bed can be worked. The greater part of it is quite siliceous. Even the purer portions of the ore contain many inclusions of white saccharoidal quartz, generally drawn out into long slender filaments. In some cases the iron appears as flattened oolitic grains, imbedded in a ground-mass of white quartzite. It is evident that in these deposits the iron existed in the quartzite before the alteration of the latter. It may have been in the form of the carbonate or of the hydrous oxide, and possibly, in part at least, of the sulphide. Some portions of the ore contain what may possibly be greatly altered pseudomorphs after pyrite. The ore is not appreciably magnetic; is nearly black in color, and has a bright metallic luster. It is called "gray ore" by the miners, to distinguish it from the brown hematites of the same district.

Brown Hematite or Limonite.—Several varieties of this ore occur in the southern Appalachians, which are more or less distinct in their appearance, manner of occurrence, and mode of formation. The most important of these are. (1) gossan-ores; (2) Tertiary gravel-ores; (3) concentration-deposits; and (4) fault-deposits. Only the two latter varieties occur in the Cartersville district, but all four of the classes occur in the immediate vicinity, and may be briefly characterized

1. The best-known deposits of gossan-ore occur in the Ducktown district. As is well known, copper occurs there associated with great quantities of pyrrhotite. The latter has been

oxidized at the surface to limonite, and during the process of oxidation the copper has been concentrated at the bottom of the weathered zone, forming the rich deposits of "black copper" overlying the unaltered pyrrhotite. The gossan-ore has a variable depth, down to 50 feet or more, and consists of soft, porous, ocher-yellow limonite.

2. During Tertiary time the valley-region was reduced very nearly to sea-level, and in its lower portions, chiefly those underlain by the Chickamauga limestone (the next formation above the Knox dolomite), swamps were formed which received drainage from the adjacent regions, and in which extensive deposits of bog-ore were formed. When the region was elevated, the limestone areas were again reduced more rapidly than the adjacent areas underlain by dolomite, and doubtless much of the accumulated iron-ore was removed by erosion. Around the margins, however, the ore remained imbedded in the residual clay. Deposits of this character are especially abundant in the Rockmart and Cedartown districts, southwest of the one represented in Fig. 1. These districts comprise a number of areas of Chickamauga limestone, surrounded by zones which contain large quantities of iron-ore. It is usually in the form of gravel-ore, composed of concretions, from the size of shot up to a foot or more in diameter, imbedded in the residual red clay, and associated with more or less chert from the underlying Knox dolomite.

3. The brown hematites of the third class, here called concentration-deposits, constitute the most important deposits of the Cartersville district. They may occur wherever a limestone is underlain by an insoluble and impervious stratum, such as sandstone or quartzite. Favorable conditions for this accumulation occur in northwest Georgia and Alabama, at the contact of the lower Carboniferous limestones with sandstones which sometimes underlie it, and at the contact of the Beaver limestone with the underlying Weisner quartzite. The Beaver limestone is more readily soluble than the formations on either side, and hence, in the erosion of the region, it has always formed valleys. At various times these valleys have received the drainage not only from the adjacent quartzite and limestone, but probably also from other of the valley-formations; and the widely disseminated iron leached from these forma-

tions during the process of decay has been transported to the limestone valley, and there concentrated upon the underlying impervious quartzite. As the surface of the limestone was lowered, chiefly by solution, upon successive elevations of the region, remnants of the ore-deposits thus formed were left, resting upon the underlying quartzite, and marking elevations at which the surface of the limestone had remained for considerable periods. These deposits are composed in part of gravel-ore, and in part of masses of considerable size, in some cases reaching many feet in diameter. Where the large masses of ore preponderate, it is probable that they represent replacements of the limestone by iron-bearing solutions, rather than ordinary bog-ore deposits. From the distribution of the ore-banks, shown in Fig. 1, it will be seen that a large proportion of them are located near the contact of the Beaver limestone and the Weisner quartzite. These generally belong to this class of concentration-ores; and this contact is marked by a more or less continuous band of ore-deposits. The red clay in which they are imbedded is chiefly derived from the limestone, and the surface is generally covered with fragments of quartzite from the higher portions of the quartzite ridges.

As already remarked, the quartzite has been considerably folded and is doubtless also intersected by numerous faults of small throw, the evidence of the faulting being chiefly the occurrence of breccias. The latter usually consist of fine angular fragments of quartzite cemented by limonite, and associated with these breccias are often found considerable deposits of iron-ore. These are sometimes irregular deposits imbedded in the residual material which covers the surface, and are not sharply differentiated from the concentration-deposits above described. In other cases, the ore appears to form well-defined fissure-veins, with distinct walls of the inclosing formation. This is notably the case at the Wheeler bank, about four miles southeast of Cartersville. The vein is from 12 to 15 feet in width, with occasional offshoots. The inclosing rock is a grey siliceous schist, with some blue curly talcose slate and quartz stringers; also occasional bands of schistose feldspathic conglomerate. The vein dips east about 80° and strikes nearly north and south, parallel with the schistosity of the inclosing rock, and with the adjacent Cartersville fault. The ore ap-

pears in part to have filled an open fissure and in part to have replaced the schist, numerous fragments of which remain in the ore-body. It consists for the most part of geoidal shells, containing many cavities with stalactitic and botryoidal forms, which have glazed surfaces showing brilliant iridescent colors. It generally has a fibrous structure, and further differs from the concentration-deposits in the almost complete absence of residual clay associated with the ore. This ore-body has evidently been deposited subsequent to the development of schistosity in the enclosing rocks, since it shows no evidence of movement in the way of brecciation or slickensides.

At no point in this district has development gone below water-level. The deposits are generally worked only to a depth permitting direct drainage. Hence the bottoms of the ore-bodies are seldom reached. Of the depth to which the four classes of deposits, enumerated above, extend, it may be stated. (1) that the gossan-ores are sharply limited by water-level; (2) that the Tertiary gravel-ores are generally superficial, the greater part of the deposits being near the surface, below which they rarely extend more than 30 feet; (3) that the concentration-deposits go considerably deeper, and, under favorable conditions, may extend to the depth of 100 feet, or even more; and (4) that the deposits associated with faults and formed in fissures are undoubtedly the deepest of all. If, as appears probable, they were formed by solutions ascending from considerable depths, they may extend downward several hundred feet, although the character of the ore would doubtless be found to undergo some change with depth; the oxide being accompanied by increasing proportions of sulphide, and perhaps carbonate.

The general belief among the ore-miners that certain of these brown hematite deposits are stratified, and may be followed under cover between other rock strata, is, of course, entirely erroneous. Also, the view which has been held* that in this and adjoining districts the deposits of brown hematite follow the outcrops of particular beds rich in iron is almost equally erroneous. The present distribution of these deposits, as shown above, depends entirely upon the geological structure

* J W Spencer, "Economic Resources of the Paleozoic Group of Georgia," *Geol. Surv. of Ga.*, Atlanta, 1893.

which determined chemical and physical conditions requisite for their deposition. In all cases the iron has been transported to a greater or less distance from the beds in which it was originally disseminated. The specular hematite above described, and the red hematites which occur at various horizons in the Silurian rocks, belong to an entirely different class of deposits

Other Ore-Deposits of the Cartersville District.

Ocher.—Intimately associated with these bodies of brown hematite are deposits of yellow ocher which have essentially the same composition, but differ in their physical characteristics. The ocher is confined to the Cambrian quartzite, and occurs along a more or less continuous band, extending from the south side of the Etowah river northward at least to Rowland Springs, and probably beyond. Since it occurs in the form of a fine powder, it makes little show at the surface; and its presence is developed only by natural or artificial cuttings, which have removed the overlying mantle of fragmental and residual materials. The best exposures of the ocher occur at the south end of the wooden bridge across the Etowah river, southeast of Cartersville. Here the river, in cutting across the quartzite ridge, has made a good natural exposure of its beds in place. The ocher has also been extensively mined at this point, so that abundant opportunity is afforded for studying its mode of occurrence. The quartzite with which it is associated has been so extensively shattered by compression that its original bedding is very difficult to determine. The ocher forms a series of extremely irregular branching veins, which intersect this shattered quartzite without any apparent system. They frequently expand into bodies of considerable size; and when the ocher is removed, rooms 6 to 10 feet in diameter are sometimes left, connected by narrow winding passages. The mining of the ocher has left the point of the ridge completely honeycombed with these irregular passages and rooms.

The contact between the ocher and the inclosing quartzite is never sharp and distinct, but always shows a more or less gradual transition from the hard vitreous quartzite, to the soft ore which may be easily crushed between the fingers. The quartzite first becomes stained a light yellow, and loses its

compact, close-grained texture. This phase passes into a second, in which the rock is perceptibly porous, having a rough fracture and a harsh "feel," and containing enough ocher to soil the fingers. In the next phase the ocher preponderates, but is held together by a more or less continuous skeleton of silica, although it can be readily removed with a pick. The final stage in the transition is the soft yellow ocher, filling the veins, which crumbles on drying, and contains only a small proportion of silica in the form of sand-grains.

The intermediate zone between the pure ocher and the quartzite is usually a few inches in thickness, although it may be several feet between the extremes, and, on the other hand, sometimes only a fraction of an inch. When the transition-rock is examined under a microscope, the character of the transition can be seen even more clearly. The more compact portions, which are only slightly stained with iron, are seen to be composed of a transparent ground-mass, threaded with minute cavities, which penetrate the rock in all directions and contain a fine dendritic growth of iron oxide. The latter occurs only rarely in isolated grains, but generally in clusters of minute grains or fibers, attached to each other and branching irregularly from a central stem. They have no trace of crystal form. Passing toward the ore-body, these minute passages become larger and increase in frequency, until only a finely branching siliceous skeleton remains, the greater part of the rock having been replaced by the iron oxide. Under polarized light, the transparent ground-mass is broken up into an aggregate of small quartz grains, penetrated in all directions by the iron oxide. The latter does not lie between the individual grains, but passes through them, as though the ground-mass were quite homogeneous. The process of replacement is never complete; for all the ocher contains more or less sand. When this is washed clean from the iron oxide, it is found to differ from ordinary sand-grains in having extremely irregular outlines. This sand, as might be anticipated from the microscopic structure of the slightly altered quartzite, is evidently composed, not of the original grains of the rock, but of detached portions of the irregular siliceous skeleton, which, in the intermediate stages of replacement, holds the iron oxide in its cavities. Aside from the silica, the ocher as mined con-

tains only hydrated ferric oxide, a small amount of alumina, and a trace of manganese oxide, the latter giving it a slightly greenish tint.

Some portions of the Cambrian quartzite contain interbedded siliceous shales, and the silica in these has also been replaced to some extent by iron oxide, producing an ocher which is inferior to that derived from the quartzite, since it contains considerable clay—practically all the argillaceous matter originally contained in the shales. Imbedded in this ore are numerous small cubes of pyrite, or rather limonite pseudomorphs after pyrite. These were probably an original constituent of the shales, before the replacement occurred.

The above-described structure of the ocher and the inclosing quartzite, particularly as observed under the microscope, throws considerable light upon its mode of origin. The forms of the residual sand-grains in the ocher, and of the siliceous skeleton about its border, were evidently produced by solution. It seems probable, therefore, that the iron oxide is a direct replacement of silica. The faulting of the region, by fracturing the rocks, afforded favorable conditions for the percolation of surface-waters to great depths; and since the faulting was doubtless accompanied by the development of considerable heat, the region was probably characterized by numerous thermal springs. The work of Van Hise and others has shown that, under favorable conditions, especially under great pressure and at high temperatures, silica becomes one of the readily soluble rock-constituents. It appears that, under certain conditions, a carbonic acid solution of iron carbonate, meeting an oxidizing solution, precipitates its iron as hydrated ferric oxide, and at the same time dissolves silica.

The conditions for this reaction seem to have been present in the Cartersville region. Water, containing in solution iron carbonate or other ferrous salts derived from the decay of surface rocks, must have penetrated to considerable depth, particularly through the shattered quartzite. But in addition to this solution of iron percolating downward from the surface, the open fissures probably afforded abundant opportunity for the free circulation of water containing oxygen. The two solutions coming in contact, the iron carbonate was oxidized and precipitated as limonite, in the place of silica dissolved at the

same time. The solution of the silica, which is the difficult part of the process to understand, may have been assisted by the presence of alkalis in the oxidizing solution. It was probably greatly assisted by the heat which must have resulted from the faulting. It is also possible that carbonic acid, in the so-called nascent state, at the point where it is freed from one compound, may be a much more efficient solvent for silica than in its ordinary condition.

Numerous open passages and cavities, penetrating the quartzite and the bodies of ocher, are met in mining. The smaller cavities are generally lined with a crust of small quartz crystals, while the larger ones frequently contain beautiful crystals of barite, which were probably deposited after the conditions favorable for the solution of silica and the deposition of ocher had passed. Groups of acicular crystals of this mineral, several inches in length, are not uncommon. It also occurs in white granular veins. The barite is called "flowers of ocher" by the miners. It remains in the residual soil which covers the quartzite outcrops, and affords the best means of tracing the ocher deposits. It is found at numerous points on the low quartzite ridge north and south of the Etowah river, and prospecting at these points has never failed to reveal more or less extensive deposits of ocher.

Manganese.—Closely associated with the above described deposits of iron-ore are extensive deposits of manganese. These have been quite fully described by Dr. Penrose,* and require only brief mention here. All the iron-ore contains traces of manganese; but the main deposits of the latter ore are quite distinct from the iron. The ore occurs, like the brown hematite, imbedded in a heavy mantle of residual clay, associated with chert and angular fragments of quartzite. The proportion of clay to ore is usually larger than in the deposits of brown hematite. The ore occurs as small concretions scattered through the clay, and also in the form of veins, penetrating the clay in an irregular manner. It has the appearance of having been deposited by solutions percolating through the residual mantle. The original source of the manganese was probably the Beaver limestone, although some of it may have come from the Weis-

* R. A. F. Penrose, Jr., "Manganese; Its Uses, Ores, and Deposits." *Ann Rept Geol. Surv., Arkansas*, 1890, vol. i, pp. 418-426.

ner quartzite. The deposits occur with about equal frequency in the residual material derived from the two formations.

Dr. Penrose holds the view that some, at least, of these deposits existed in their present form in the rocks of the region before weathering, and are therefore strictly residual. While this may be true in a few cases, the writer has found no evidence of it in the field; and the manganese ores are regarded, like the iron-ores with which they are associated, as purely secondary deposits, their distribution being determined chiefly by chemical and physical conditions, rather than by the outcrop of beds especially rich in manganese.

Although, in the aggregate, a large amount of ore has been mined from this district, most of the work has been done in a primitive and inefficient manner. It is probable that, with modern appliances, a large amount of material would pay for working which does not contain a sufficiently large proportion of ore to be profitably worked by the present methods.

An Examination of the Ores of the Republic Gold-Mine, Washington.

BY T. M. CHATARD AND CABELL WHITEHEAD, WASHINGTON, D C

(Washington Meeting, February, 1900.)

THE Republic mine, situated forty miles from Marcus, a station on the Spokane Falls and Northern Railroad, in the north-eastern part of the State of Washington, was located in 1896, but no development-work was done until the spring of 1897. While much of the ore mined since then has been rich enough for shipment to smelters, a method of locally treating the lower-grade ores soon became a matter of prime importance, because only about 40 per cent. of the values could be recovered by plain amalgamation, even with ores assaying 4 to 5 ounces of gold per ton. Experiments with cyanidation, in various ways, led to the adoption of the Pelatan-Clerici process and the erection on this system of a 10-ton experimental plant, which was later increased to a capacity of 35 tons per day. The extractions by this process showed much improvement over previous work, especially when the ore was crushed to

120-mesh; but the general results were not very satisfactory to the owners, since the extractions on rich ore were not over 85 per cent., falling as low as 70 per cent. with the \$30 ore. In the search for the cause of these losses and for improvement of methods, samples of these ores were sent to us for examination.

The ore, as received by us in September, 1898, consisted in great part of grayish-white lumps and fragments of chalcedonic material, intermixed and coated with a softer friable substance, having the appearance of amorphous silica. It could be easily crushed to pass a 100-mesh screen, but even in this state of fineness the most careful panning failed to show more than a minute quantity of sulphurets; no free gold could be detected, even with a powerful magnifying glass, although our assays showed a value of 6.30 ounces per ton. Careful search proved the absence of arsenic, antimony, tellurium and selenium, and there appeared to be no chemical reason why the gold should not be easily extracted by cyanide. Moreover, when a sample of the ore was treated with hydrofluoric acid, the gold in the residue was clean and bright, and, under the microscope, showed indications of crystallization.

The ore was then crushed to pass 60-mesh, thoroughly mixed, sampled and assayed, giving a value of 6.30 ounces gold and 6.15 ounces silver per ton. Twenty-five pounds were then treated in the Aurex sluice, recently described by us,* the strength of the cyanide solution used being 0.286 per cent. KCy and the duration of the run being one hour. The tailings assayed 2.10 ounces gold and 2.80 ounces silver, an extraction of only 66.66 per cent. gold and 54.49 per cent. silver—a result quite inexplicable, considering that the gold was apparently perfectly free; the test was therefore repeated, using a stronger solution (0.376 per cent. KCy) and increasing the time of treatment to two hours, but with no better results. Crushing to 80-mesh showed some improvement, the tailings assaying 1.45 ounces gold and 1.90 ounces silver, indicating the advantage of still finer grinding. We therefore ground the remainder of the ore to pass 100-mesh, and then, on treatment, obtained tailings which assayed 0.48 ounce gold and 1.02 ounces silver—an extraction of 92.38 per cent. gold and 83.41 per cent. silver.

This first lot of ore having become exhausted, more was

* "Notes on the Aurex Sluice," *Eng and Min Jour.*, February 3, 1900, p. 138.

obtained, part of which was mill-pulp, assaying 2.50 ounces gold and 3.75 ounces silver; the rest being coarse ore, assaying 2.30 ounces gold and 2.50 ounces silver. As fine grinding seemed to increase the extraction, the mill-pulp, which had been ground to pass 120-mesh, should have been peculiarly fitted for treatment; but the best results in the sluice gave tailings assaying 0.40 ounce gold and 1.55 ounces silver, or an extraction of 84 per cent. gold and 41.3 per cent silver. Since, however, the percentage of extraction increased with the fineness of grinding, it was fair to presume that the residual values were mainly contained in the coarser portions of the tailings, which were therefore separated into sands and slimes, there being about 60 per cent. of the latter. To our surprise, the two portions assayed practically the same, although the gold in the sands could then be extracted by percolation with comparative ease. In view of this observation, another portion of the pulp was taken, mixed with the cyanide solution, allowed to stand overnight, and then run as before. The tailings assayed 0.25 ounce gold and 0.75 ounce silver, the values being confined mainly to the slimes.

It now became necessary to devise a method of treating these slimes, and, as they remained in suspension for an indefinite period, some means of precipitating them was needed. Neither lime nor common salt gave good results; so sulphuric acid was tried. A slight effervescence was noted, and a small portion of the suspended material appeared to go into solution, while the rest began to subside; on making the solution alkaline, the material flocculated and subsided rapidly. On repeating this experiment with the original ore, we found that the acid solution contained alumina, oxides of iron and lime, while the residue, on panning, showed much free gold, although none could be found in the untreated ore. As the acid appeared to liberate the gold, it was at first supposed that carbonate of lime was the masking agent; so another portion of ore was calcined before cyaniding. Great improvement was noted, the sluice extraction being brought up to 94.60 per cent. gold, the tailings assaying 0.135 ounce gold per ton. These were separated into slimes and sands as before, the slimes now settling quickly and containing only 0.05 ounce gold per ton. The sands amounted to 50.6 per cent. of the whole, percolated freely, and were treated with cyanide solution, giving a further extraction of 0.058 ounce gold, and making a total extraction of 96.92 per

cent. gold, or a final value in the tailings of 0.077 ounce gold per ton.

We now found that our coarse ore contained no carbonate of lime and yet that calcining had the same beneficial effect, the calcined ore showing, on panning, much free gold, and giving a good extraction in the sluice. It became, therefore, evident that it was not carbonate of lime, but some other constituent of the ore, which interfered with the extraction of values until it was either removed by acid or rendered innocuous by heat.

A sample of the coarse ore was finely pulverized, and the metallic iron present removed by a magnet. Ten grammes were then digested on the water-bath for one hour with hydrochloric acid, diluted with an equal bulk of water, and then filtered. The washed residue was then digested with a hot solution of sodium carbonate, to extract any silica rendered soluble by the acid treatment, while the acid solution was evaporated to dryness to recover any dissolved silica. The solution was then analyzed by the usual methods, and the complete results were as follows

Insoluble residue,	.	.	.	.	.	.	97	11
Soluble silica,	.	.	.	.	.	.	0	31
Alumina,	.	.	.	.	.	.	0	33
Ferric oxide,	.	.	.	.	.	.	0	40
Ferrous oxide,	.	.	.	.	.	.	0	29
Copper,	.	.	.	.	.	.	0	016
Zinc,	.	.	.	.	.	.	0	025
Lime,	.	.	.	.	.	.	0	066
Magnesia,	.	.	.	.	.	.	Tr	
Sulphur,	.	.	.	.	.	.	0	060
Phosphoric acid,	.	.	.	.	.	.	0	018
Water,	.	.	.	.	.	.	1	53
Total,	.	.	.	.	.	.	100	155

This analysis indicates that the material which envelops the gold and prevents its dissolving in the cyanide consists mainly of hydrated oxides of aluminum and iron, since the amount of "soluble" silica is insufficient for any known combination with the bases, even if we suppose that all of it was originally so combined. The sulphur probably exists partly as sulphides of iron, zinc and copper, partly as sulphates, but the small amount of the total made it hardly worth while to determine the proportion. Some of the lime may exist as carbonate; but the amount of this must be very small, since no effervescence could be noted upon treating the ore with acid.

In the *Engineering and Mining Journal*, Dec. 16, 1899, p. 726, the following analyses, A and B, of Republic ores are given, an analysis by us, C, being added for comparison

	A	B	C
Silica,	85 61	90 55	94 41
Alumina,	6 37	4 73	2 95
Iron oxide,	3 16	2 57	1 29
Copper,			016
Zinc,	Tr		025
Manganese,		20	Tr
Lime,		90	06
Lime carbonate,	4 37	.	
Sulphur,	04		06
Water,		1 20	1 14
Total,	99 55	100 15	99 951

Analysis A shows, as do many of our own tests, that the Republic ore often contains much carbonate of lime, but our work has convinced us that this substance is not the cause of the low extractions, which are really due to hydrated oxides of aluminum and iron. As a rule, the gold and silver in these ores are in the form of very minute particles, and these appear to be so enveloped in the slimy hydrates as to be floated off by the water when the ore is panned, the hydrates also forming a coating impervious to cyanide solutions. When the ore is treated with acid the hydrates are dissolved, and the gold, thus set free, is easily collected in the pan. The action of heat, by driving off the water of hydrates, leaves the oxides in a brittle and porous condition, so that they either separate from the gold or permit the cyanide solution to reach and dissolve it. Calcining has, however, the reverse effect upon the silver, as the extraction of this metal was always less after the ore had been heated than before, due probably to the conversion of sulphide of silver into metallic silver, which is less easily soluble in cyanide than the sulphide.

While the results of this investigation have given interesting suggestions as to the genesis of this remarkable deposit, a discussion of that topic is foreign to the purpose of this paper, which is to call attention to the importance of thorough chemical examination of such gold-ores as, without apparent cause, do not readily yield their values to the usual processes. Proper investigation will always show the cause and rarely fail to indicate the remedy.

The Enrichment of Gold and Silver Veins.¹

BY WALTER HARVEY WEED, BUTTE, MONT

(Washington Meeting, February, 1900)

INTRODUCTION.

IN a previous paper upon the enrichment of mineral veins by later metallic sulphides,† the writer has shown that certain masses of rich ores, such as are found in many mines, either near the water-line or as bonanzas in depth, are of secondary origin, and are due to a leaching of lean ore and the concentration of the material by reaction between the solution and the unaltered ore below. The geological and mineralogical evidence is believed to form an adequate basis for a chemical and physical explanation of the phenomenon. In the present paper the writer will give a brief synopsis of this theory, and will apply it more particularly to deposits of the precious metals, laying special emphasis upon the dependence of such enrichments upon the presence of iron sulphide (as pyrite, etc.) in the primary ore, and upon structural features which control the circulation of the enriching solutions below the water-level. It is believed that many, though not all, of the bonanzas and pay-shoots of rich sulphide ores, especially those carrying gold and silver, which are encountered in ore-deposits, are of such secondary origin. Apparently it is essential that the occurrence and structural relations of such ore-masses should be understood, as the success of the mine is often dependent upon the finding and extraction of these ores. A legitimate deduction, too, is that such ore-deposits decrease in value with depth.

As my own studies have been mainly in Montana, my illustrations must be drawn from the ore-deposits of this and adjacent States, with such as I have noted in hurried visits else-

* Published by permission of the Director of the U. S. Geological Survey.

† *Bulletin Geological Society of America*, vol. XI., pp. 179-206, 1900.

where. The literature of ore-deposits doubtless affords also many illustrations of secondary deposition besides those quoted by me in this paper. The recognition of secondary enrichment as a factor, and the chief one, in the genesis of many rich ore-deposits was forced upon me several years ago by my study of the Neilhart, Mont., silver-gold veins. Since then it has proved to be of frequent occurrence in many mines, and its study has led me to the theory of secondary enrichment propounded in a previous paper, and especially applied to precious metals in this paper

STATEMENT OF THE PROBLEM

The fact that masses of very rich ore often occur near the water-line in many mines, but do not continue in depth, and the occurrence of pay-streaks and bonanzas in deep mine-workings, is a matter of history in many regions. The problem is to explain the genesis of such ores. The theory here presented accounts for such ores as enrichments formed from bodies of lean ore of complex composition, which have been lixiviated, the gold, silver and copper being carried downward below the water-level and precipitated as high-grade sulphide ores. The evidence is mainly mineralogical and geological, but it is in entire accord with chemical tests and reactions, which have been carried out in the laboratory or are too well known to be called into question.

Surface-waters are believed to be commonly the means by which the lean ores are leached and the metallic contents carried down and redeposited. In some cases, however, concentration has probably been effected by new fractures, resulting, in the cases known to the writer, from later volcanic activity and faulting, and serving as channels for upcoming hot waters. As commonly understood, "surface-waters" are those which have so recently left the surface as to still retain constituents common to waters now found at or near the surface (free carbonic acid, organic acids, chlorides, etc.), and which produce an oxidation. Thus the effect of superficial alteration, as described by most writers, has been the production of carbonates, chlorides, oxides, etc. In those instances where surface-agencies have had a reducing effect, it has been commonly ascribed to organic matter, though Penrose cites the formation of native copper by the action of "a ferrous salt on certain copper salts,"

as an instance where the primary chemical action is one of partial oxidation, and the reducing action follows, as the effect of one of the partially oxidized compounds on the other. In this sentence lies the pith of the whole subject of enrichment, since when the leaching of lean ore is performed by oxidizing surface-waters the resulting solutions percolate downward as deoxidized waters, carrying soluble salts that are the result of oxidation, and enrichment is the result of a reaction between these substances in solution and the unaltered ore with which they come in contact in their downward course. Above the ground water level there is a constant movement of the water downward, but below that level the free oxygen has commonly been used up.*

THE ZONES OF WEATHERING, OF ENRICHMENT, AND OF PRIMARY SULPHIDES.

At the outset a sharp distinction must be drawn between the secondary or later enrichment herein described, which occurs in part at the water-level but usually below it, and the enrichment due to simple weathering or superficial alteration of the ore. In the latter case the gold or other values remain, while the worthless constituents are in large part removed, thereby greatly increasing the value per ton of the weathered part of the vein. This process, usually known as superficial, is a common and now well-known feature of ore-deposits the world over.

In order to describe the different parts of veins here under discussion, the writer will follow common usage in calling the upper weathered part the zone of weathering. Beneath this lies the zone of enrichment, underlaid in turn by the zone of primary sulphides. The term "zone" is, of course, only used for convenience, since it is well known that weathering extends down along fractures and other channels for circulating waters, sometimes for hundreds of feet into a mass of otherwise unaltered ore. The zone of enrichment is even more irregular, and may, as illustrated in the ideal conditions represented in

* It should be noted that the word *oxidation* is here used in its original restricted sense, as it is commonly understood, and not in the extended sense used by chemists to express the converse of reduction, as, for instance, Cu_2S to CuS where no oxygen is present.

the diagram, Fig. 1, be separated by unaltered ore from a bonanza mass of secondary ore beneath.

The occurrence of enrichments between altered and unaltered vein-matter is one that has not escaped the attention of previous writers; but they have all, so far as known to me, limited such enrichment by the ground-water level. Thus, Penrose says *

"As a result of these various changes, certain minerals are sometimes leached from the upper part of ore-deposits which have become porous by alteration and carried down to the less pervious unaltered parts. Here they are precipitated by meeting other solutions or in other ways, and hence the richest bodies of ore in a deposit often occur between the overlying altered part and the underlying unaltered part. This is not always the case, but it is true of some copper, silver, iron and other deposits "

This author, it is true, recognized that surface-waters pass below the zone of oxidation and may gradually sink to very great depths below the permanent water-level. But he expressly declares that the results of such circulation do not relate to superficial alteration,† which he limits to that of deposits that remain *in situ*.‡ De Launay, in his very interesting and valuable essay,§ has given us a chemical theory, to the support of which he has marshaled all the facts gathered in the preparation of his great monograph on ore-deposits. This author distinctly recognizes a zone of enrichment, but, like Penrose, limits it by the permanent water-level (*niveau hydrostatique*).

Leaching in the Zone of Weathering.

In the sulphide enrichment here discussed, the enriched material is in most cases derived by the leaching out of the metals from the portion of the vein lying above ground-water level. This leaching is due to superficial alteration, and leaves the iron as a goossan while the waters carrying the gold, silver, copper and other metals in solution trickle downward through the partially altered ores into cracks and water-courses which penetrate the ore-body below the water-level. The first part of the process is, therefore, the leaching of the lean ores which occurs

* *Journ. Geol.*, vol ii, 1894, p 294

† *Loc. cit.*, p. 298.

‡ *Loc. cit.*, p. 302.

§ "Contribution a L'Etude des Gîtes Métallifères," *Ann. des Mines*, 9th series, vol. xii., 1897, pp. 119-227.

in the superficial alteration of the vein. This has been discussed by many writers, particularly by Penrose, who, however, does not make any attempt to state the chemical reactions involved. These reactions are complex, and the mass results depend upon the laws of physical chemistry; yet the general

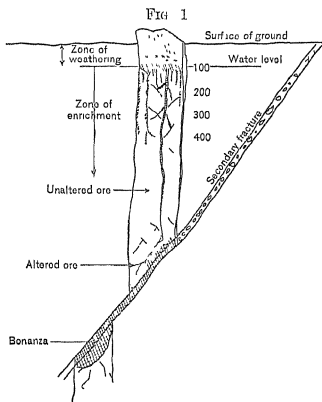


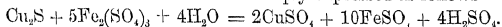
Diagram Showing Relative Positions of Zones of Weathering, Enrichment and Unaltered Ore, and of Bonanzas Formed Along Fault.

changes involved may be expressed by equations showing end reactions.

The chemistry of weathering, concisely expressed, is as follows. In an ore consisting of either one or all of the following sulphides:—pyrite, arsenopyrite, chalcopyrite, blende, galena, tetrahedrite,—the minerals will oxidize according to their relative affinity for oxygen and inversely as their “affinity” for sulphur.* All the sulphides will be attacked simultaneously,

* This statement is sufficiently accurate for the purposes of this discussion. As the mineral decomposition is affected by physical structure, as well as chemical, and by relative amounts of each present, it is apparent that there are many qualifying factors. The “relative affinity” of the metals for sulphur is 1 Hg, 2 Ag, 3 Cu, 4 Sb, 5 Sn, 6 Pb, 7 Zn, 8 Ni, 9 Co, 10 Fe, 11 As, 12 Mn. This is the order in which a salt of one metal will be decomposed by any subsequent one in the series and the first metal precipitated as sulphide. (See *E. and M. Jour.*, Oct. 25, 1890, p. 484. See also *Jour. of Soc. Chem. Ind.*, vol. xi., 1892, p. 869.)

but, inasmuch as pyrite consists of 4 parts ferric and 1 part ferrous sulphide,[†] and parts with a portion of its sulphur very readily, this mineral will be most attacked. This decomposes first to FeS and S. The sulphur usually forms H_2SO_4 ; the FeS forms $FeSO_4$. The latter changes to H_2SO_4 , $Fe(OH)_3$, and $Fe_2(SO_4)_3$. The sulphuric acid attacks more iron sulphide and forms more $FeSO_4$ together with H_2S —the latter, in the presence of abundant oxygen, forming H_2SO_4 . The $FeSO_4$ changes to $Fe_2(SO_4)_3$, which attacks the sulphides of copper, lead, zinc, etc., in a reaction which can be most simply expressed as follows



The H_2SO_4 in mine-waters will attack both copper and iron sulphides and form sulphates without the formation of H_2S or the liberation of free S; and the iron sulphate, oxidizing the iron, is precipitated as limonite. The oxygen may come from either air or water. $PbS + Fe_2(SO_4)_3 = PbSO_4 + 2FeSO_4 + S$; or $PbS + 4Fe_2(SO_4)_3 + 4H_2O = PbSO_4 + 8FeSO_4 + 4H_2SO_4$. And $ZnS + Fe_2(SO_4)_3 = ZnSO_4 + 2FeSO_4 + S$, or, more probably, $ZnS + 4Fe_2(SO_4)_3 + 4H_2O = ZnSO_4 + 8FeSO_4 + 4H_2SO_4$.

The above equations simply show that ferric sulphate can oxidize the various sulphides to sulphates, and is itself reduced to ferrous sulphate. However, the sulphuric acid formed by the oxidation of pyrite in the upper zone can also attack sulphides, and the H_2S which is formed may be oxidized by the ferric hydrate into sulphuric acid. This method is probably more likely of occurrence, but no one can say that the oxidation is exactly according to any set of equations, as many other reactions are possible.

The laws of physical chemistry, verified by experiment, show that blende is more easily attacked by oxidizing waters than galena, and the latter mineral decomposes more readily than chalcocite. The general order of attack of the sulphides is therefore arsenopyrite, pyrite, chalcopyrite (FeS removed, leaving CuS), blende, galena, chalcocite, while tetrahedrite, being a complex substance without definite percentage-composition, has no fixed place. Gold, if present, may be attacked by $Fe_2(SO_4)_3$ in which it is well known to be readily soluble, and silver goes

* "The Chemical Composition of Marcasite and Pyrite," by Amos P. Brown, *Proc. Am. Phil. Soc.*, vol. xxxiii, p. 225, 1894

into solution as sulphate. The lead, which as sulphate is nearly insoluble and remains about its parent-mineral galena, can only migrate when reduced to carbonate (by calcite, etc.), in which condition it is readily carried off by carbonated waters.

Where these are the only reactions, the outcrop is leached of all its metallic matter, and its soluble gangue-minerals are reduced to a porous spongy mass of silica, such as is sometimes seen. Commonly the iron is not all removed, since the ferrous sulphate, which is the most abundant product of the leaching, absorbs oxygen and water and forms limonite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ (or rarely a basic sulphate of iron), forming the iron-stained quartz or limonite gossans, the "iron cap" of so many vein outcrops. This leaching of the ores is therefore seen to depend upon the tendency of the iron salts to form $\text{Fe}(\text{OH})_3$ as an ultimate product which is precipitated from the solution; thus renewing the FeSO_4 , which renews the ability of the solution to attack more pyrite and metallic sulphides. This cycle of change can be tentatively expressed as follows: Ferric sulphate forms by the oxidation of the iron sulphide of the original ore. This salt attacks pyrite and other sulphides, and is itself reduced to ferrous sulphate. The latter oxidizes to ferric sulphate, which is partly changed to limonite and sulphuric acid, while the remainder begins anew the cycle of change. Ferric sulphate is the main vehicle by which the sulphides are dissolved. The $\text{Fe}(\text{OH})_3$ is *in part* eliminated as a precipitate, while a part is acted upon by the sulphuric acid with the production of a solution holding $\text{Fe}_2(\text{SO}_4)_3 + \text{FeSO}_4$, these iron sulphates being in the approximate proportion of 3:1. The FeSO_4 takes up oxygen and forms $\text{Fe}(\text{OH})_3$, and the ultimate production is a yellow basic sulphate insoluble in H_2SO_4 . The result of these changes, due to water and abundant oxygen, is the leaching out of all the constituents of the vein in the weathered zone except iron and silica. The solutions seeping downward contain various metallic sulphates and much sulphuric acid, the amount of the latter being increased by that formed by hydrolysis from the sulphates, since copper sulphate in solution yields sulphuric acid.

Precipitation in the Zone of Weathering.

Not all the material leached out in the zone of weathering migrates below to the zone of enrichment; for the surface-

waters commonly contain carbon dioxide, some chlorides, organic matter, etc., resulting in the formation of carbonates, chlorides, etc., and of the native metals. Thus, copper can be formed from the oxide by reaction with either free sulphuric acid or iron sulphate (both abundant in the lower part of the superficial zone), viz. $\text{Cu}_2\text{O} + \text{H}_2\text{SO}_4 = \text{Cu} + \text{CuSO}_4 + \text{H}_2\text{O}$; and $3\text{Cu}_2\text{O} + 6\text{FeSO}_4 = 6\text{Cu} + \text{Fe}_2\text{O}_3 + 2\text{Fe}_2(\text{SO}_4)_3$. The latter reaction accounts for the cement-copper associated with iron sesquioxide at Ducktown, Tenn., Gold Hill, N. C., and elsewhere. Native silver is also formed in films and crystalline masses by reduction through ferrous sulphate, viz. $\text{Ag}_2\text{SO}_4 + 2\text{FeSO}_4 = 2\text{Ag} + \text{Fe}_2(\text{SO}_4)_3$. Gold probably sometimes occurs in the native state because it has not been attacked and is simply left behind, though it is also deposited by precipitation from the ferrous sulphate solution.

The Zone of Enrichment.

The surface-waters which have leached the vein in the zone of weathering seep downward along cracks and crevices, or along trunk-channels, into the primary ore below. The origin and occurrence of such fractures will be mentioned later. They very commonly exist in ore-deposits, and convey waters downward far below the so-called ground-water level. As we have shown, these waters not only carry various metals in solution, chiefly as sulphates, but they are no longer oxidizing, but are of acid reaction. Penetrating the primary ore, they come in contact with the unaltered metallic sulphides. In such masses pyrite and, more rarely, pyrrhotite are very commonly abundant, and a reaction at once occurs between the iron sulphide and the metallic salts (mainly sulphates) held in solution, resulting in their decomposition and the precipitation of new sulphides which encrust the walls of the fractures. This, in the case of copper, is shown by the following theoretical equation, which expresses end reactions only, viz. $4\text{CuSO}_4 + 3\text{FeS}_2 + 4\text{H}_2\text{O} = 2\text{Cu}_2\text{S} + 3\text{FeSO}_4 + 2\text{H}_2\text{SO}_4 + 2\text{H}_2\text{S} + \text{S}$, or, more simply, copper sulphate and pyrite yield copper sulphide and ferrous sulphate.* This Cu_2S would react in turn upon silver sulphate, $\text{Ag}_2\text{SO}_4 + \text{Cu}_2\text{S} = \text{Ag}_2\text{S} + \text{Cu}_2\text{SO}_4$, while the pyrite

* The apparent anomaly of cupric sulphate and pyrite giving ferrous sulphate is explained by the chemical composition of pyrite as 4 parts ferric sulphide and

itself will decompose the silver as well as other sulphates, owing to the relative affinity of the metals for sulphur. Chloride or carbonate of silver would be similarly decomposed. For the rich antimonial sulphides of silver various reactions are possible, the pyritous ore reducing the minerals from a solution holding antimony and arsenic derived from impure pyrite. This process is probably aided by the free sulphuric acid brought down in the waters and as hydrolyzation-product of intermediate steps of above reactions; since a dilute solution of sulphuric acid attacks iron sulphide, forming iron sulphate and sulphuretted hydrogen, the latter of which would form sulphides of lead or silver, etc., from the solutions.¹

For lead the presence of carbonates seems necessary, and if the gangue minerals are of this nature, or the walls are limestone, the lead carbonate is decomposed, lime goes into solution, and the H_2S set free from pyrite at once forms galena, which is deposited.

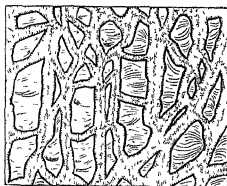
The Solution and Precipitation of Gold.—The alteration of gold-deposits presents features differing very markedly from those accompanying the alteration of copper- or silver-ores. It is commonly assumed that the unaltered ore contains the gold in association with pyrite or quartz. The most frequent alteration of this is to a rusty brown mass of sesquioxide of iron, permeating the quartz and holding nugget-threads of free gold. As a result of further alteration by surface-waters, the iron is leached out, and a porous, spongy, white quartz remains, holding the gold. This kind of alteration is a very common feature of ore-deposits throughout the West. In many cases, however, different conditions prevail. Part of the gold, at least, is taken into solution by ferric sulphate, carried downward as the waters

1 part ferrous sulphide, the latter only being herein considered. Moreover, we may have in oxidation zone $Cu_2S + 4Fe_2(SO_4)_3 + 4H_2O = (Cu_2SO_4)_2 + 8FeSO_4 + 4H_2SO_4$. Then any sulphide would precipitate Cu_2S from the cuprous sulphate, providing the sulphide is soluble enough and the sulphate solution is strong enough to have enough cuprous ions and sulphide ions to exceed the constant of solubility. The formation of cuprous sulphate is theoretical, but its existence is indicated by recent experimental work, as yet unpublished, by C. F. Tolman, Jr.

" It must be understood that these equations are given in the simplest and most compact form possible. Thus $CuSO_4$ in water really holds $(Cu(OH)_2$ and H_2SO_4 .

seep below, and precipitated as native, leaf, wire or scale gold in minute cracks in sulphide ores, or, what is more commonly the case, the gold is deposited with silver in antimonial sulphides, especially ruby silver (pyrargyrite). This is the form in which it occurred at the Ruby mine, on Lowland creek (near Butte), where the surface of the quartz crystals lining the open spaces between boulders of decomposed rhyolite and coating these boulders is liberally sprinkled with ruby silver. This mine yielded \$600,000 in less than a year, of which one-half the value was gold. The ore was a secondary concentration along a clay fault-fissure, and is now exhausted. The "indicators" of Australian ore-deposits afford a most interesting

FIG 2



Alteration of Bornite to Chalcocite and Lamonite, Blue Wing Ore, Virginia District, N. C. The nucleal masses are bornite, the black borders represent chalcocopyrite; the stippled area is non oxide. Drawn from nature, twice the natural size.

example of the reduction of gold by pyrite. These indicators are thin layers, sometimes but half an inch thick, of pyrite occurring in shale. In many cases the shales are, it is true, carbonaceous, and the organic matter may assist in the reduction. As shown by Don and by Rickard, the quartz veins are barren except where they intersect these pyritous layers.*

The experiments of Liversidge† have shown that gold is precipitated from solution more readily by metallic sulphides than by organic matter.

* J. R. Don, *Trans*, xxvii, p. 569. T. A. Rickard, *E and M Jour*, 1895, lx, p. 561.

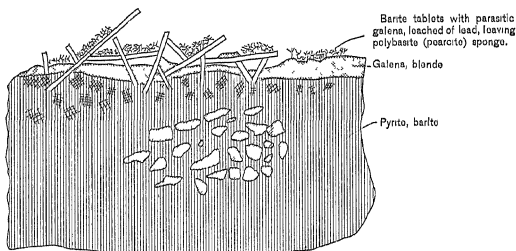
† *Proc. Roy. Soc. N S W*, vol xxvii, 1893, p. 287. See precipitation of gold by pyrite in the experiments of Dantree, quoted by Rickard in "Origin of the Gold-Bearing Quartz of Bendigo Reefs," *Trans*, vol xxii, p. 313.

Résumé.—It seems unnecessary to expand this section further, as the reactions given are sufficient to show that secondary sulphides are formed in depth. It is evident that a majority of the reactions depend upon the presence of iron sulphides, either as pyrite or in some other form. Pyrite is therefore the great precipitant of secondary sulphides.

EVIDENCE THAT CERTAIN MINERALS AND ORES HAVE THE GENESIS STATED ABOVE.

That chemical reactions similar to those given do take place in nature, and that the resulting precipitates are true minerals, is shown by abundant mineralogical proof. Thus the auriferous copper-ores of Gold Hill, North Carolina, show chalcopyrite

FIG 3



Specimen Showing Leached Galena and Residual Polybasite; Florence Mine, Nelhart, Montana

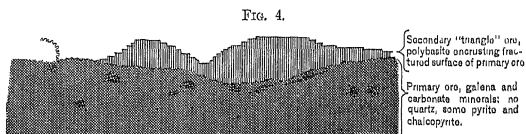
altering about its borders to a spongy mass of black copper sulphide, the iron being largely carried off, but in part forming hematite nests near by. In other specimens, the copper sulphide has gone into solution, and has been carried a few inches and redeposited in crystalline masses. In a similar manner bornite alters to chalcocite and iron oxide, as shown in specimens from the Blue Wing mine at Virgilina, Person county, North Carolina. Fig. 2, drawn from nature, shows this alteration. In other specimens the iron is carried off and fills cavities with specular iron-ore.

At Nelhart, Montana, polybasite and pyrrargyrite encrust barite, quartz, galena and pyrite, which are themselves later

than and encrust fractured masses of impure galena, blende and pyrite that constitute the original vein-filling. These crusts are now forming in vugs and water-courses filled by sluggish descending water. Nucleal masses of impure galena are seen in thin section surrounded by a spongy mass of polybasite, just as chalcopyrite is seen surrounded by amorphous copper glance. Fig. 3 is a diagrammatic representation of a portion of the surface of a specimen of ore from the Florence mine. The main mass of the specimen consists of a breccia of pyrite fragments, held in a cement of barite and ankerite spar, with scattered grains of galena. The upper surface shows galena, blende and barite, the latter in projecting tablet-shaped crystals upon which there are parasitic masses of impure argenterous galena. This galena is etched and leached so that, on part of the specimen, the surface shows a crust of about $\frac{1}{16}$ to $\frac{1}{8}$ inch thickness consisting of a spongy residue, or a skeleton of the galena. This spongy mass consists largely of polybasite left behind as the more soluble lead was leached out. That some of the antimonial sulphide of silver goes into solution, is shown by the presence nearby of minute newly-formed crystals of the latter. The crystalline polybasite occurs nearby coating fractures and showing characteristic triangular markings, or as loose aggregates of rough and mossy-surfaced crystals. It is also probably derived from blende, as it occurs very commonly coating that mineral under conditions which seem to preclude precipitation by that mineral. An examination of numerous specimens from the Florence and Big Seven mines shows that polybasite and pyrargyrite are secondary minerals filling cavities and cracks in the original ore. The material gathered from the lowest level of the Florence mines shows polybasite in the form of crystalline tablets upon barite and other minerals, and also as a moss-like mass of open skeleton-texture, which seems to represent arrested deposition. The latter form is believed to come from a place in the vein where mineral-bearing water is now depositing this mineral, together with spar, quartz, and probably galena. Studied under the microscope, the polybasite appears to be an alteration-product of galena, and itself to be mixed with, and to grade into, pyrargyrite, which is in some cases its undoubted alteration-product. It is certain that polybasite, as the important constituent of many of the ores, is of

secondary origin. It occurs on all other minerals, and is itself not coated or dotted by them. Fig. 4 is a diagram of a specimen of the common ore of the district consisting of galena and carbonate "spar" with scattered pyrite and chalcopyrite. The specimen is from the wall of a fracture traversing the somewhat friable bands of galena. The surface of the fracture has been coated with a thin drusy covering of quartz upon which there rests massive polybasite whose upper surface shows the typical triangle striations of polybasite. The specimen is drawn nearly to natural scale.

Sphalerite also occurs in well-formed crystals in some of the vugs and is one of the most recently deposited minerals.

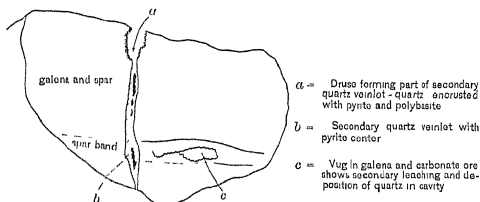


Specimen from the Florence Mine, Neihart, Montana

While polybasite and pyrargyrite are economically the most important of the secondary minerals formed by enrichment-fractures in the Neihart ore, yet other minerals, galena, pyrite, blende and quartz, are also formed. An excellent example is seen where quartz veinlets have filled fractures in the primary ore. Fig 5 shows a piece of the common spar and galena ore in which the ore is fractured and the fissure filled by a veinlet of quartz in whose center pyrite is seen. At the top the fissure is open and the vug is lined with a drusy coating of quartz, on the surface of which occasional larger crystals of polybasite are seen. The druse (*c*), connected with the quartz veinlet by a fracture following a layer of spar, shows secondary quartz and pyrargyrite. Where such fractures traverse the ore, and its carbonate gangue is at a decided angle to the banding of the deposit, and the crusts or filling are notably different in composition, there is no doubt of their being of later origin. A veinlet of this kind is illustrated on a natural scale in the diagram, Fig. 6. In this case various secondary minerals were formed. The figure represents a cross-section of a little quartz

"vein" of the Big Seven mine, which constitutes the high-grade ore-streak of the lode. It shows the relative abundance and association of the minerals, but does not represent the spongy texture of the polybasite and its intimate admixture with both galena and pyrites (chalcopyrite), as this growth is too mossy to be represented well, and the mineral is therefore indicated as polybasite alone. The specimen, seen in thin section, shows ruby silver and polybasite intimately associated and forming irregular, shreddy and ragged patches. No positive identification of galena as the nucleus of such masses was made, but the association with galena is such as to indicate a possible change to polybasite. The pyrite is broken and frac-

FIG 5



Specimen of Silver- and Lead-Ore from Neihart, Montana

tured, but the grains are always sharply defined, and no genetic relation to the silver sulphides is recognizable. A blende crystal, seen isolated in the central quartz-filling, shows in thin section a crust of polybasite, the latter holding minute inclusions of pyrite. The blende, seen in another section of rich ore, is invariably surrounded by a dark crust which is not iron oxide, nor does it appear to be an iron-rich blende. It is not definitely determinable, but resembles galena or a silver sulphide.

Posepny has described stalactitic deposits of sulphide, which, as urged by Dr. A. Schmidt,^{*} form excellent proof of the formation of secondary sulphides by a leaching of ore in the zone of weathering and a redeposition of ore in the zone of enrichment. Posepny, it is true, denied such an origin for these deposits because they occurred below water-level. The

^{*} *Die Zinkerzlagernstätten von Wiesloch, in Baden, Heidelberg, 1881, p. 94*
 Posepny, *Genesis of Ore Deposits*, p. 63, and *Trans.*, xxiii, 259

existence of open spaces below water-level is a phenomenon frequently encountered in ore-bodies exposed by mine-workings. I myself have seen such openings a foot or more across at 1000 feet below the water-level at Elkhorn, Montana, and at 200 feet below water-level at Neihart. The pipe-ore of Raibl described by Posepny is, I believe, an excellent example of the formation of secondary minerals by descending waters. Posepny's explanation that they are due to ascending waters which were denied access to the cavity except through the roof, seems to me to be an hypothesis opposed to both the facts of observation and physical laws. Moreover, as the geology of the mining regions is more carefully studied, it is certain that they have passed through various physiographic changes, with migration of water-level, so that air-filled spaces below what is now the water-level are not only possible but in some cases probable.*

Prof Vogt also describes† the recent concentration of gold and silver in a zone beneath the "iron hat." He says that in the Rio Tinto region the "iron hat" is from 35 to 50 meters deep, and consists of iron oxide or hydrated oxide, with from 35 to 50 per cent. of iron, some silver in part as basic sulphate, and a few ten-thousandths per cent. of arsenic, while on the other hand the copper-contents are, as already remarked, entirely oxidized and dissolved out. In one mine, North vein No. 2, at Rio Tinto, there occurred between the iron hat and the underlying comparatively fresh pyrite, a layer of earthy, porous material, bearing gold and silver. This earthy ore, though a few decimeters in thickness, may be followed continuously over the entire ore body. This very marked layer follows closely the irregular plane between the iron hat and the underlying pyrite. It everywhere contains an average gold- and silver-contents of from 15 to 30 grammes gold and 1.025 silver, with a value of about 150 marks per ton. In stripping off the "iron hat," this earthy mass is carefully laid to one side, and has thus yielded fully a thousand tons of ore. It is clear that the formation of this gold- and silver-bearing zone is connected with the oxidizing process that formed the iron hat, and that the gold and silver comes from the very small percentage of such metals in the primary ore.

* Posepny, p. 53; and *Trans.*, xxiii., 260. | *Zeitsch. Prakt. Geol.*, July, 1899.

Deductions.

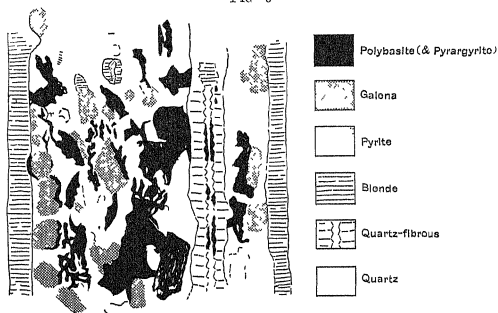
From the chemical reactions given, it is evident that enrichment is largely dependent upon the presence of marcasite, pyrite or some other form of iron sulphide in the primary ore, since lixiviation depends upon the presence of the iron sulphates, and precipitation is mainly effected by the unaltered sulphides. As a consequence of this, it follows that ore-bodies lacking in iron pyrites will not show enrichment, thus explaining the absence of any such phenomena in the pure silver-lead bodies of the Cœur d'Alene district and elsewhere. In this region, visited by the writer in 1895, the ore-bodies consist of galena with a siderite gangue and are replacement-deposits in quartzite and argillaceous schists. The veins are covered by great masses of barren limonite gossan, beneath which the ores are carbonates and sulphates of lead, which extend along fractures to a depth of 200-300 feet. The silver values, which carry about 10 ounces of silver to 1 per cent of lead, do not show any enrichment. This is quite what would be expected, since, although the galena in decomposing would yield up silver as sulphate, there would be no reducing agent at hand to extract it from the waters as it seeped down into the unaltered ore. Also, at Barker, Montana, the ore-bodies show no enrichment, though a common feature of such deposits, viz., the change of galena to pyrite, in depth, would favor enrichment, if the silver-lead bodies were deeply enough weathered. The writer has also examined the Zosel mines in andesite porphyry near Deer Lodge, Montana, and those in similar rocks on Basin Creek, and near Elliston, as well as the Castle Mountain and Elkhorn ores in limestone, and the Bear Paw ores in basalt, all in Montana, as well as the McMakin in North Carolina. These deposits all consist essentially of galena without any notable amount of pyrite, and although favorable physical conditions for enrichment occur, no bonanzas or pay-streaks of rich secondary ores are found.

The Occurrence of Bonanzas and Pay-Streaks.

The location of bonanzas and pay-streaks of secondary sulphide-ores is dependant upon physical factors. From a consideration of the processes described in the preceding pages, it is evident that the localization of enrichments will depend

wholly upon structural conditions. If the vein consists of a solid unshattered impermeable body, with no fractures by which the solutions can seep down into the underlying original sulphides, the zone of enrichment will be confined to the vicinity of the water-lines, and, if above water-level, will constitute the ore-bodies described by Penrose, De Launay and others as one of the results of superficial alterations. In fact, many such enrichments do occur at, or just below, the water-level. If the primary ore-body is shattered by cracks, sheeted by later movement or traversed by secondary fractures, faults running with

FIG 6



Secondary Veinlet of Quartz and Rich Sulphide Ore Filling Fracture in Primary Ore; Big Seven Mine, Neihart, Montana. Pyrite and galena are angular fragments of original ore

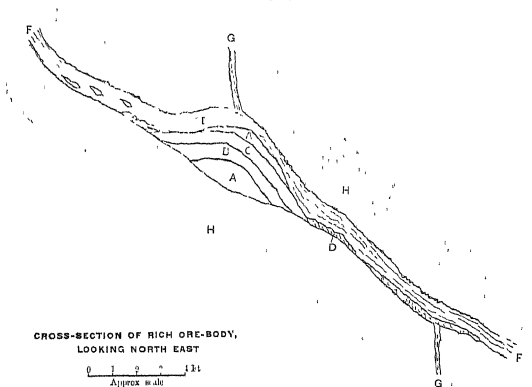
or across the vein, such crevices and fractures will be the channels in which the descending solutions will travel, and along which the secondary ores will form deposits in the unaltered ore below

Such secondary fractures may be now filled with quartz or other gangue-minerals holding ore, or they may be barren and open, or they may be marked by a soft mushy mass of clay or attrition breccia. Very often the so-called splits, feeders and stringers of a vein, when examined critically, will be found to be secondary fractures and not true offshoots of the vein itself, the latter phenomenon often being the cause of ore-shoots of primary origin. Where the later fracturing runs parallel to

the vein, as is so often the case at Butte, and in the silver mines of Jefferson county, it may only be revealed by a clay selvage of a rare shakenside surface, though it is more frequently marked by a soft and mushy mass of mud and breccia, in which fragments of the wall-rock ore and gangue, one or all, may be seen. This is seen at the Comet mine, where secondary ores were abundant along recent fissures filled with clay and a breccia of leached ore and altered wall-rock.

An excellent example is afforded by the ore-body of the Australian Broken Hill Consols mine, New South Wales, described by Smith.¹ The occurrence of the largest bonanzas yet

FIG 7



Australian Broken Hill Consols Mine, New South Wales (After George Smith, *Trans.*, xxvi, 73.)

A, dyscrasite; B, stromeyerite, C, decomposed amphibolite, etc., assaying under 7 oz. per ton; D, fahlerz, E, soft gossany material, containing nodules of silver chloride, stromeyerite, etc., and averaging about 750 ozs. per ton, F, limonite, practically free from silver, G, cross-vein, H, amphibolite

found in the mine were in association with the vertical vein G, shown in the diagram (Fig. 7). This cross-vein has been faulted by the lode, and is really a succession of joints along a line of

¹ *Trans.*, xxvi, 69.

weakness. Another bonanza occurs in the same mine, 500 feet to the east, under similar conditions.

Mr. Smith's statement is that the lode itself is only ore-bearing where it makes junction with cross-veins. The well-known occurrence in Australia of ore-bodies where veins cross "indicators," *i.e.*, pyritic bands a few inches wide, is readily understood, either as secondary enrichment or primary, since the reducing effect of pyrite upon gold held in solution has been established by Liversidge.

The part played by such secondary fractures at Butte can hardly be appreciated by those not familiar with the ground. In descriptions and diagrams of the veins of this district the occurrence of clay and breccia bands and walls has not been

FIG 8

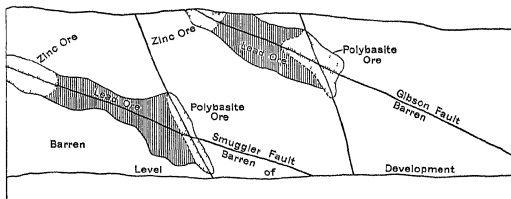


Diagram to Show Relation of Molhe Gibson and Smuggler Ore-Bodies and Bonanzas (of Polybasite) to Fault-Fissures. (From Spurr.)

overlooked, though their true significance appears to have escaped notice since the fractures so often run parallel with and in the vein itself. Emmons first noted the significance of such fractures, and their genetic connection with glance and bornite veins. It is now known that these fractures are extensive laterally and vertically, and the enrichment probably due to them extends in some instances to a depth of 2000 feet below the present surface. Lest this statement prove misleading, it should be qualified by adding that not all such fractures have caused enrichment, and some of the largest fault-fractures are of relatively recent formation, later than the ore-bodies of glance and bornite, etc., which they cross.

In his monograph upon the Aspen district, Colorado,* Mr.

* J. E. Spurr, *U. S. Geol. Survey, Monograph No xxxi., Geology of the Aspen Mining District.*

Spurr describes the occurrence of the famous ore-bodies of the Smuggler and Molhe Gibson mines at Aspen, Colorado. The ore consists of barite and polybasite, with tennantite. Although Mr. Spurr gives no definite statements as to the possible secondary origin of these ores, yet the sketch which he gives¹ (Fig. 8) and the descriptions all indicate that the original ore was a silver-bearing lead sulphide, with more or less iron and zinc sulphides, formed along inclined faults, and that subsequent to the formation of these ore-bodies, nearly vertical faults displaced the ore and formed the two bodies now worked at the mines mentioned. Although in these vertical or nearly vertical fissures rich polybasite ore is now found, it does not extend far in either direction from this fault; and the description of the ores given by Mr. Spurr indicates that it is derived by secondary alteration-processes from the lead and zinc ore-bodies. This is also indicated by the fact that the polybasite is in part altered to native silver at the extreme lower end of the ore-body.

In conversation with me, Mr. Spurr has admitted the possible secondary origin of these polybasite bodies, but had no new evidence upon the subject. He says

"This ore was of a rich character, having large amounts of polybasite and native silver. This polybasite body appears to lie in a sort of subordinate shoot, trending south of east and lying at the Gibson fault-plane. This shoot is marked by exceptionally large and rich bodies of a nature not found elsewhere in the mine. It is noteworthy that this rich shoot is practically the lower termination of the ore of the Gibson fault. Most of the ore below this is native silver, which, from the nature of its occurrence, is manifestly a secondary deposit leached from the rich ore above. Some of these secondary deposits are, however, of considerable size, and empty vugs are often found beautifully and elaborately festooned with delicate wires of silver. Above the polybasite ore, however, the ore appears to be pretty continuous, but the amount of silver becomes less."

It will be noticed that he recognizes the secondary nature of the silver, and that the polybasite lies between the native silver and the lead sulphide.

In a chapter upon the chemical geology of the region, where he discusses the alteration of the ore-deposits and of the limestones, he does not adduce any new facts concerning the formation of the polybasite ore; but he does say that iron pyrites carrying small amounts of arsenic, lead, copper, zinc, cadmium,

* *Op. cit.*, 183.

cobalt and nickel is found, and that tetrahedrite is also very common. The polybasite is said to be later than the barite.

The description given by Leggett* of the Rosario mine, San Juancito, Honduras, C. A., shows that the secondary enrichment may account for the peculiar features of the deposit. This fissure-vein splits into two distinct veins in more barren ground and unites into one consolidated vein where ore-bodies occur and where feeders enter from the hanging-wall—a condition paralleled in the Drum Lummon lode in Montana. The oxidized ore of upper levels includes frequent streaks of argentite and the rich silver sulphides. The lower levels show the unchanged sulphides of iron, copper, lead and zinc. The gangue is quartz, carrying in the ore-bodies occasional clay-streaks, heavily stained with the hydrated oxides of iron and manganese. Other accompanying minerals found less frequently are polybasite, embolite, etc. The vein-material is quartz pure and simple. The foot-wall is usually decomposed and broken, and a clay parting often runs a foot or two inside of the wall, necessitating close stulling till the stope can be filled with waste. The conditions noted here are the counterpart of those encountered in the copper-veins of Butte, where later fractures, marked by clay and attrition-breccia, have been the channels for enriching solutions.

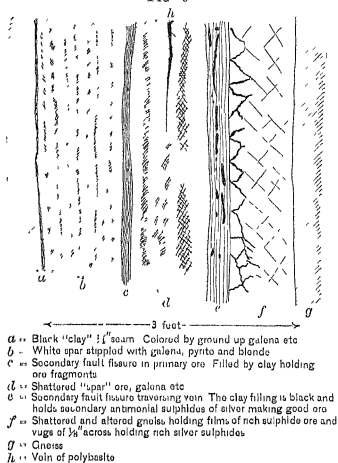
The Secondary Enrichment of Veins at Neihart, Montana.

Secondary enrichment has played an unusually important part in the development of the ore-deposits of Neihart. The ores extracted in the earlier workings and those found to-day where new veins are opened, all show silver sulphides deposited by secondary enrichment as crusts or crystals lining cavities, or as films or thin coatings along fractures of the primary ore, or in the oxidized zone as the so-called "sooty sulphide" ores that occur with manganese oxides. It is from this zone of enrichment that the high-grade ores, running from 200 to 1000 ounces of silver to the ton, or even higher, were obtained in the early history of the camp. Although such ores gave out in depth and caused many disappointments and failures, their occurrence played a most beneficial part in the development of the veins.

* *Trans.*, xvii., 432.

The secondary minerals recognized are chiefly polybasite (really pearceite) and ruby-silver, the former being more abundant. There are also bright metallic coatings, presumably argentite, on crystals and along fracture-planes, and rarely in minutely crystalline masses. The superficial alteration of the Neihart veins is not a marked one, as there are no great zones of carbonates and oxidized ore. Such ores occur only in limited amounts, being most abundant in the Broadwater vein, where

FIG 9



Face of Broadwater Vein Exposed August, 1897, on Stope Below Third Level.

the partially oxidized ores extend down 170 feet below the outcrop, and, in pipes and along drainage fissures, reach even greater depths. Generally, however, there is another zone of alteration below the level of these altered or highly altered ores—the zone of enrichment. This secondary ore also occurs in the cracks of the shattered country-rock, forming the vein-matter where it is associated with secondary quartz (Fig. 9). Very commonly the polybasite occurs in crystalline masses showing no definite crystal outlines. In the open spaces and

vugs of the vein, crystallized specimens have been found associated with barite. It is possible, of course, that this may be due to the meeting of surface- and of deep-seated waters. The zones of impoverishment, of enrichment, and of unaltered primary sulphides recognized in the case of the copper veins are clearly present here, though the uppermost is of limited extent, and the zones are not so sharply or definitely separated from one another as they are in copper deposits, owing to the later fissuring of the vein-filling allowing the secondary enrichment to be mixed with the unaltered sulphides. Polybasite is said by Dana to alter to stephanite and pyrite. In the Neihart ores the mineral seems to show an alteration to pyrargyrite and pyrite, and the former, in turn, changes to native silver in the upper zone.

An example of the economic necessity of carefully observing secondary fractures and accompanying enrichment is shown by the Eva May mine, on Cataract creek, near Boulder, Montana. In the early history of the mine much high-grade ore was found consisting of pyrite, together with more or less galena, blende and chalcopyrite, the whole impregnated with scattered bunches of rich antimonial sulphides of silver. The vein is a large one and shows thick ore-shoots of pyritic ore, but the bulk of this away from the enriching fracture is too poor to work. Concentrates made from it have, according to analysis in the Survey laboratory, the composition shown under I. in the following Table.

Silica, Alumina, etc.	} Insoluble, Part of ore,	I Per cent.	II. Per cent.
		19.81 50	10.31 .56
Fe,	24.08	23.59
Pb,	9.83	23.93
Zn,	6.00	5.74
Cu,	4.56	1.29
Bi,33	.12
Ni,03	trace
Ca,	none	none
As,	2.01	.98
Sb,55	trace
S,	32.30	33.48
		100.00	100.00
Gold, ounces per ton,10	.75
Silver, " " " "	1.85	7.25

This material, which looks so much like good ore, has caused the mine to shut down. It will be seen that it furnishes an admirable material for alteration and concentration of silver according to the process outlined in the first part of this paper. In point of fact the pay-streaks and pay ore-bodies of this property are of secondary origin, and it is only by confining mining operations to such places that the mine can be made to pay.

Another example is the Frohner mine, 10 miles south of Helena, at the head of Clancey creek. The main ore is a mixture of galena and pyrite, and occurs in sufficient abundance to warrant working, if it were not too low in grade. Yet the primary ore, where not enriched, will not pay for concentration. The composition of this ore is given in column II. of the table on the preceding page. The ore has been concentrated until it carries but 10.3 per cent. silica, with iron and lead present in nearly equal proportions. The sample was carefully collected, so as to represent a true average of the concentrates as shipped. The rich ore of the mine, carrying as high as 200 oz. of silver per ton, was found near secondary fractures, and consisted, I am told, of pyrite and galena with films and nests of antimonial sulphides of silver.

A considerable list of mines in Montana might be mentioned in which such phenomena have been observed by the writer. Of many others the past history shows rich surface-ores, becoming rapidly leaner in depth. This is true not only of silver mines, but of gold-silver properties, near Marysville, Montana, in California at the Mojave mines, etc.

Where telluride ores occur, the only enrichment observed has been due to superficial alteration, as has been observed in the Judith mountains, Little Rocky mountains, the Dolcoath mine near Elkhorn, and the Mayflower mine, all in Montana.

The Effect of Physiographic and Climatic Changes.

Active degradation favors the accumulation of enrichments, while prolonged degradation of a region, resulting from physiographic revolutions, may result in successive migrations of material and the accumulation in a relatively shallow zone of the metals derived from many hundreds, and possibly thousands, of feet of the vein worn away in the degradation of the

land. Climatic conditions, rainfall or aridity, warmth and rapid alteration of vein fracture are agents affecting surface-weathering, and hence, also, enrichment.

Active degradation of a region, that is, rapid weathering, favors enrichment by the quickness with which it removes the upper already leached part of the vein, so that a larger amount of vein matter is lixiviated in a given time than would result from slower wasting of the land. Such enrichments are favored by high altitudes. Moreover, the mountainous regions are those in which secondary fractures are most apt to be found.

Changes of Water-Level

Prolonged degradation is favorable for a similar reason, since time is a factor in enrichment, and changes in elevation, etc., affect the rate and progress of decay of the vein; while the crustal movements accompanying physiographic changes favor fractures of the earlier deposit, which give facilities for leaching and spaces for deposition. If a region passes through several cycles of erosion and elevation, it is evident that their result is likely to be a succession of enrichments in which not only the original ore is leached, but the earlier enrichment-deposits migrate downward. At Butte, Montana, the region has passed through several very pronounced changes in elevation since the formation of the veins in tertiary time. In early Tertiary time the present topography was blocked out, and the mountain ranges and deep intervening valleys were carved. This was succeeded by earth-movements by which the streams became clogged or the valleys dammed, forming lakes; while volcanoes broke out at numerous places and showered ashes and scoria over the region. The valleys were silted up or in part filled by volcanic débris, before crustal movements drained the valleys and altered the divides. More recent movement, possibly still continuing, is marked by faults and a reversing of stream-courses. The old valley at Butte is filled by hundreds of feet of débris, and a mountain wall 2500 feet high marks a north and south fault-line. These changes all caused a migration of water-level facilitating the processes of weathering and enrichment, and the great bodies of rich copper-ores of the region are believed to be in part due to this cause.

Types of Copper-Deposits in the Southern United States.

BY WALTER H. WEEB, BUTTE, MONTANA

(Washington Meeting, February, 1900)

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INTRODUCTORY.

IN the early history of this country the existence of copper in the Appalachian region was well known, but no mining was attempted until the discovery of the Ducktown deposits in

1850. The richness of the black copper-ore of that locality led to an exploration of similar gossan-covered deposits elsewhere, and as long as these rich ores lasted the deposits were vigorously worked.

Meanwhile the discovery of gold in California greatly increased interest in the Appalachian gold-field, and placer-working was followed by the opening of a large number of quartz-veins. These gold-ores, which were free milling in the upper, oxidized, weathered parts of the veins, changed at the water-level to pyritous ores in which but part of the gold was free. Notwithstanding this fact, many of the veins were worked to considerable depths. Frequently, however, the sulphide ore carried an increasing amount of copper pyrites as the mine became deeper, and since this could not be successfully amalgamated, or rather since the percentage of gold was too small to be profitable, such properties were promptly abandoned when the percentage of copper in the ore reached about 2 per cent. In the last thirty years, many unsuccessful attempts have been made to work these veins for gold and copper. Failure has been due to a variety of causes, but the chief reason has been the low price of copper. With the marked increase in the price of this metal which has resulted from the widespread and marvellously rapid introduction of electricity throughout the world, there has also been a decrease in the cost of metallurgical treatment, due to improved methods of smelting and refining. The result has been renewed interest in copper-deposits. The Southern field contains many properties which, under present conditions, offer as satisfactory prospects of profit as many in the West; a number of the abandoned gold properties being of this class. At the same time the great pyrrhotite bodies of Ducktown and similar deposits elsewhere are workable under these improved conditions.

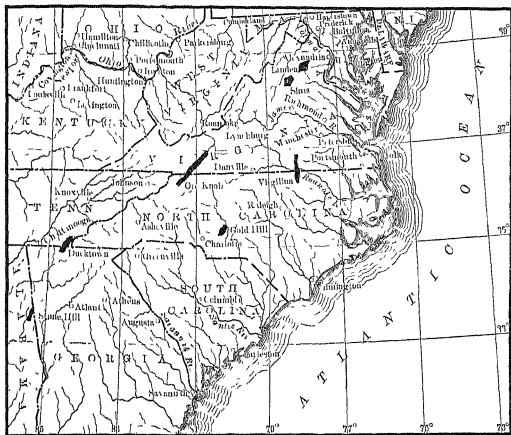
The writer, having visited a few of the many copper-deposits of the Carolinas, has been impressed with the fact that no attempt has been made to present a general account of the copper-resources of the region. As the deposits present marked differences, which have an important economic bearing and which permit a grouping of the deposits according to their similarity to certain types, the attempt will be made in the present paper to describe representative examples of each type

from material gathered during personal observation, and to point out the types to which the deposits belong that have been described by others in State reports and scientific papers

Fig. 1 is an index-map showing the locations of the deposits described.

The localities described were visited during the last four months of 1899 in a search for data bearing upon mineral alteration and redeposition, and the time spent at each locality

FIG 1



Index-Map, Showing the Location of the Copper-Deposits Described.

was necessarily brief, being only sufficient for a survey of the general characteristics of the deposits, though the notes thus accumulated convinced the writer that a discrimination may be made between the different types represented in the copper-deposits of the South. The notes here given should be regarded, therefore, only as a slight contribution to our knowledge of the ore-deposits of the South and not as a finished study of their features. I shall, therefore, briefly outline the characters of four different types to which, I believe, many others of the region may be referred. I think it will be apparent that if these

types can be established much repetition in description will be saved, and the ore-deposits will be studied to better advantage.

SUMMARY OF TYPES.

1. The first type of deposit is that of a true fissure-vein, the quartz-vein—formed by the filling of open cavities, with only minor and accessory replacement of country-rock. The Virgilina deposits are representative of this type. The ore is glance and bornite, without chalcopyrite or pyrite. The veins cross the schists or conform with them.

2. The second type is that of auriferous quartz-veins common in the Appalachians. Although true fissure-veins, they are formed by the replacement of country-rock along sheeting-planes or true fissures, and accompanied by the filling of open cavities as a minor and accessory feature. It is named from the Gold Hill mines, where such veins have yielded several millions in gold.

3. The third type is a pyrrhotite-vein—a true fissure-vein the filling of which is essentially pyrrhotite or pyrite, almost barren of quartz, and represents the replacement of a zone of sheeted rock which was composed largely of metamorphic minerals.

4. The fourth type comprises local segregations of native copper, copper oxides and carbonates along shear-zones in altered igneous rocks. Such deposits, so far as known, do not extend below the groundwater-level in depth.

I. THE VIRGILINA TYPE.

The Virgilina Copper-Mines.

Location.—The copper-mines of the Virgilina district, in Halifax county, Virginia, and Granville and Person counties, North Carolina, take their name from the little town of Virgilina, situated upon the line between the two States. The Danville division of the Southern railway passes through the town, which is 47 miles east of Danville. The Norfolk and Western and the Richmond and Danville roads lie not far to the north and west.

The topography is hilly, or undulating, like much of the Piedmont plateau. The mines thus far developed all lie upon

a so-called ridge, which is a somewhat flat-topped elevation of 100 to 250 feet above the neighboring stream-valleys, and is from one-half to two miles or more in width. This ridge is cut by numerous cross-drainages and stream-hollows, and it is only at the northern end near the Hyco river, where it is called High Hill, that its elevation above the surrounding country is quite apparent.

Water is abundant in winter, but quite scarce in summer, when most of the small creeks run dry. At the town of Virgilina the wells have been sunk at least 80 feet. The mines make but little water, and if the district is ever developed so as to become a large producer there will be some difficulty in obtaining a sufficient supply. The Hyco river is the nearest available source.

Much of the district is timbered with hard wood, and locally with pine, but the timber has been largely culled and it is only in small tracts that it is found of sufficient size to serve for mining purposes. The land is owned in large tracts, usually of several hundred acres, the title to which carries, of course, the mineral ownership.

History.—The district has been more or less prospected for the past 40 or 50 years, as shown by the pits and shafts now found for 8 miles north, and as far south, of the State line.* The Gillis mine was opened in 1856,† and a fine body of glance-ore was exposed. The district remained practically unexplored, however, until 1897, though considerable money was spent there in 1886–87, when the Blue Wing mine was opened, and 500 tons of ore were extracted. Some prospecting was also done on the Yancey mine; but unfavorable reports were made by experts, and the property remained idle until 1897. In that year the district was again the scene of active operations, and 225 car-loads of ore were taken out and shipped to the Orford Copper Company.

The Rocks of the District.—The country-rock is schist, in few places massive enough to be called gneiss. Natural outcrops are rare and seldom more than 2 or 3 feet high, forming sharp

* See W. B. Phillips, *Eng. and Min. Jour.*, Apr. 1, 1899, p. 382, also *Amer. Manuf.*, Mar. 17, 1899.

† "Geology of Midland Counties of N. C.," *Geol. Survey of N. C.*, E. Emmons, 1856, p. 34.

and narrow reefs, persistent for short distances only. The soil is, however, thin; and the rock is encountered at a slight distance beneath the surface. In the railroad-cuttings the strike of the schists is readily determined, and varies from N. 10° to 20° E, the dip being from 70° to 80° eastward. In general, the cleared fields show much white quartz-débris along the line of the vein-outcrops, and rather massive angular blocks, from 6 inches to a foot across, of dark-colored, quite dense gneiss, which is recognizable as a volcanic breccia at one or two localities. The schists weather readily in the railroad-cuts, under the influence of frost, slacking to fine micaceous débris, which, of course, explains the absence of outcrops over so much of the region. As shown by mine openings, the rocks are superficially altered to depths of 30 or 40 feet, but this alteration does not result in the soft saprochites seen in other parts of the South, the rocks being hard and firm when freshly exposed. In color they vary from grey, the more common tint, to purple and green. Locally, they consist of massive epidote rocks of the usual pistachio-green color.

The rocks are all of igneous origin—even the softest and most shaly show this character in thin sections under the microscope. But in a few instances only is the igneous nature of the schists recognizable to the eye. This was observed at the Thomas mine, where a purplish rock is clearly a porphyritic meta-andesite. These schists are cut by dikes of later igneous rock (diabase). The only one seen by the writer was that exposed in the Blue Wing mine; other observers, however, have reported the occurrence of other dikes, with different general trends. Apart from the dikes, however, I would say, on the strength of field-observations alone, that the rocks are of igneous origin, and belong to the various porphyries which have been discovered in the Appalachian belt. This conclusion is confirmed by the microscopic examination of thin sections, which has shown the rocks to be altered andesites, that is meta-andesites and andesite tuffs.

The Veins.—The district has many veins, which do not, however, commonly outcrop, and cannot be traced throughout the entire extent of the district. Those of the High Hill and Yancey are exceptions to this rule, having well-defined outcrops

which can be followed for a mile or more in each case. In driving over the region, one notices the abundance of white quartz, distributed in well-defined belts which correspond in a general way to the outcrops of the quartz-veins. In general, there are a large number of veins which are more or less parallel, having a course of N. 5° to 10° E, and arranged with overlapping ends. These veins cross the country-rock in part, and in part are parallel to the schistosity. There is no gossan, as commonly understood, and the surface-outcrops of quartz are not much altered, but are solid and massive.

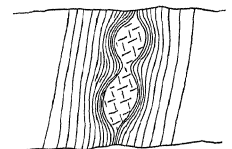
The discoveries of the past three years show that copper occurs in almost all of these veins in greater or less quantity. The most northerly point is the High Hill property, 9 miles north of Virgilina. The Yancey property is an equal distance south of this town, and other properties similar in character are said to have been found 5 or 6 miles still further south. It is certain, however, that the ores occur in a belt at least 18 miles in length, and about one mile wide. The veins are lenticular deposits of quartz, connected, and forming in some cases very uniform continuous quartz-outcroppings at the surface. The veins of the district are not persistent in width, and, with the exceptions noted, it is somewhat doubtful if they are all persistent for long distances as continuous bodies of quartz. In general, they show a lenticular structure, which is well illustrated by a little example in the railroad-cut near the town of Virgilina. This quartz-seam follows the plane of schistosity, and is cut across by the railroad, so that it shows on both sides of the track. Fig. 2 shows the bulbous or lenticular form of the quartz. The decomposition of the schists adjacent to it emphasizes this by the concentric shelling of the material about it. This structure is seen on a large scale at many of the mines. Where the schists are crossed by the main street of the town of Virgilina, small stringers of quartz are noted; and the schists adjacent to this quartz show green and blue copper-stains when broken open.

These veins, like the gold-veins generally, appear to be a succession of lenses connected by strings of quartz. The explanation given by Becker seems to be an adequate one, and is graphically shown by Fig. 3, in which *a* represents an irregular fracture traversing the metamorphic schists, but along which no

movement has taken place, while the vertical section, *b*, shows the left wall to have moved relatively upward, and the right wall downward, producing lenticular spaces by a simple faulting amounting to a very few feet. In the case of the Blue Wing vein and others in the same district, the fracture has not been a simple one, and the lenticular spaces are in part filled by the sheeted country-rock. This structure is illustrated in the ideal diagram, Fig. 4.

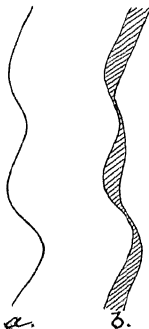
The veins are all of the lenticular type. The largest show outcrops nearly continuous for a half mile to a mile or more,

FIG 2



Quartz Lenticle of Vein Exposed in Railway-cut, Virgilina, Va., Showing the Conformity of the Enclosing Schist

FIG. 3.



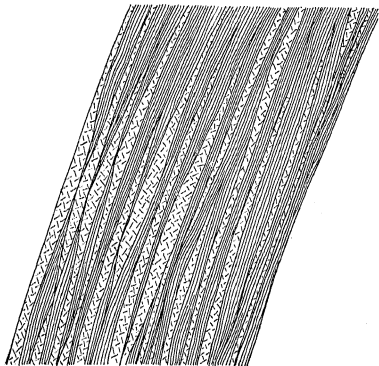
Diagram, Illustrating the Formation of Lenticular Openings by Movement of Fissure-Walls.

and underground workings show a continuous body of quartz; but even these largest veins have a bulbous or lenticular form, the vein pinching and widening both horizontally and vertically. The smaller veins show this very markedly, and their lenses are often connected by a mere film or plate of quartz, which may be wanting in certain horizontal cross-sections, so that the vein appears to have given out. In the largest veins, such as the High Hill, the outcrop is wanting in certain places, probably by reason of this thinning out.

The veins frequently show a very marked banded structure. This is commonly seen near the walls, though it often prevails

for the entire width of the vein. This banding is due to included plates of altered schist, which are often so thin as to be mere films, or dark streakings in the white gangue. These films are often marked by ore, and in some cases appear to be replaced by dark quartz, unlike the white quartz of the vein. Very frequently this banded structure is most marked where the gangue consists largely of calcite. It is shown in Fig. 4. In some cases it appears as if a slight movement had torn apart the walls in a ragged way—as a network—and quartz had filled in between the sheets of rock.

FIG. 4.



Diagram, Illustrating the Structure of Veins Formed by the Tearing Apart of Schist Included Between Fault-Fissures, or Adjacent to Fissures.

The quartz is commonly cased in a shelly micaceous material, locally called slate. The films are parallel to the quartz and wrapped around it. In some cases this material is undoubtedly the schist; but more often it appears to be either an altered fault-mud or attrition-material, possibly laminated by the pressure of the crystallizing quartz mass.

The foot-wall is generally well-defined. In the Blue Wing it is regular in dip and strike, and shows only slight undulations. The hanging is much less regular, and swells out around the lenses. The cross-dike of the Blue Wing interrupts the foot-

wall and deflects the hanging-wall, which becomes irregular as the vein passes through the tough rock. In the Holloway, which is a cross-vein, the foot-wall is not regular, but runs in and out as harder or softer bands of schist are crossed by the vein.

Slickensides were observed where the Blue Wing vein crosses the dike on the 150-foot level. The hanging-wall of the Holloway vein above the second level, north, shows flutings, whose dip is about 70° to the south. The ore-shoots have a similar dip. No clay selvage was observed at any of the mines, but water commonly penetrates the vein along the foot-wall.

The veins have a generally uniform strike of N. 3° to 5° E. The Holloway is an exception, running N. 20° E.; and there is also a cross-vein on the Yancey property.

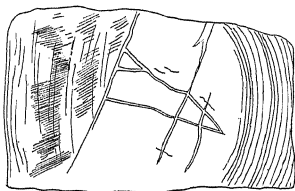
Notes on the Mines.—Figs. 19 to 22 inclusive show the nature of the surface-improvements. The following mines deserve special mention.

1. The Holloway mine, $3\frac{1}{2}$ or 4 miles S. of the town, is the largest mine of the district. A branch of the Southern railway runs from Virgihna to the mine, so that the ore is now loaded directly upon the cars. This mine belongs to W. E. C. Eastis, of Boston, who acquired control of it about three years ago. Under the superintendency of Mr. Battershall, it has been developed from a prospect-pit, 47 ft. deep, to a mine 300 ft. deep, and has yielded about 6000 tons of ore, averaging over 12 per cent. for the second-class ore and running up to 30 per cent. or more for the No. 1 ore.

The mine is equipped with steam-hoist, pumps and air-compressor, together with necessary buildings. It is developed by three levels, at the depths, respectively, of 75, 150 and 200 ft. below the surface. The fourth, just begun, is at the bottom of the shaft, 300 feet below the surface. Each of these levels is over 100 feet in length north and south of the shaft, No. 1 being 250 feet long. The vein varies greatly in width, showing the lenticular structure noticed on a small scale in the railroad cut, and, in fact, repeated in the ore-body itself. It varies from 3 ft. to 75 ft., or more, in width. In general, there is a fairly defined foot-wall, showing a dip of 75° . The hanging-wall is less defined; and both foot and hanging show irregularities, due doubtless to the crossing of the schists by the vein at a slight

angle, and the presence of projections where the rocks are slightly harder than the usual schists. It should be remarked also that the course of the Holloway vein, N. 15° to 20° E., is not that of most of the veins of the district. In the lower or third level of the mine, the vein is 12 feet wide at the south

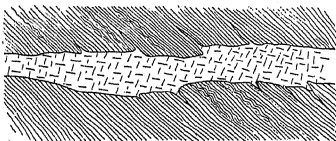
FIG. 5.



Face of the 300-ft. Level, South, in the Holloway Mine, January 26, 1900. On the left, black quartzose ore; in the center, white quartz stringers in black gangue.

face, and shows white and gray quartz, with epidote and gray chalcocite 2.5 ft. wide. Fig. 5 represents a sketch made in the mine at this level. Here the hanging-wall is rolling, and there is no defined foot-wall. It is also noticed that the quartz sends

FIG. 6.



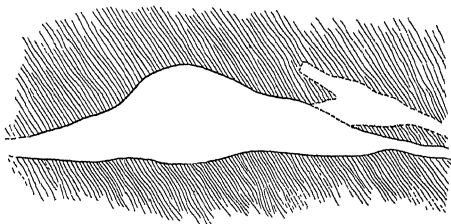
Ideal Horizontal Cross-Section of the Holloway Vein, Showing Quartz Spurs following the Foliation of the Country Schist.

little droppers or feeders into the schists, in stringers parallel to the schistosity. This is illustrated in Fig. 6.

On the third level, S. of the shaft, the vein was lost in following the foot-wall, so that there is a short cross-cut into the country-rock. Fig. 7 shows the cross-section of the ore-body on this level, to the south. In general, it is noticed

that the vein S. of the shaft is well-defined and has good walls, up to the first level. The quartz is cased in a soft, micaceous slate, which is not a gouge or selvage in the ordinary sense, and may be a schist forming part of the country-rock. I regard it, however, as more likely to be due to an alteration of the sheared country-rock, since it seems to be continuous across differing bands of schist, and to be a constant accompaniment of the quartz. On the third level, the vein pinches toward the shaft to about 3 ft., and continues with this width to the shaft and northward for a short distance, beyond which it widens to 6 or 8 ft. in width. North of the shaft, the vein is broken by an inclined fault-plane, marked by a mud containing sharp angular fragments of ore

FIG. 7.



Sketch of Cross-Section of the Hollow Vein, as Seen in the 300-ft. Level, South.

and quartz, and dipping E. about 30° . It does not throw the vein, though it shatters the walls.

The ore-body in the third level is altered along cracks showing films of green carbonates in both the ore and the white quartz. In the bottom of the shaft, however, no decomposition was observed. A prospect-drift, which has been started about 25 ft. above the face of the third level, shows a black jaspery rock, with crossings of white quartz. There is no ore exposed except on the north wall, where there is a slight green stain.

On the second level south no timbering exists, so that it was not accessible. North of the shaft, a cross-cut 8 ft. into the hanging-wall shows hard, finely laminated micaceous schists, the schistosity of which makes an angle of about 30° with the

vein At the north end of this level the vein shows a slaty hanging-wall, with quartz feeders running off into it. These feeders wedge off in a few feet, and usually carry ore. The quartz ore-body does not show any marked breccia, but in this, as in all the mines of the district, there are the usual thin, plated masses of decomposed schist. In general, the richer ore is found near the foot-wall. No definite association was observed between the occurrence of ore and the character of the various schists cut by the vein.

On the first level, 75 ft. below the surface, S of the shaft, the vein is 133 ft. wide, but converges rapidly in both directions. The present output is 30 to 40 tons of ore a day. This is picked and cobbled, and 18 to 20 tons per day are shipped, the remainder being thrown on the dump, awaiting some means of concentration. An air-compressor, running 7 drills, is at work, and a bucket-hoist is used in the inclined shaft. The mine is situated on a rather gentle slope, so that facilities for dumps are not especially good. About 120 men are employed, in two shifts of ten hours each. Labor costs 75 cents a day for common miners, and \$1 a day for machine-drill men, timber-men, engineers, and shaft-men. Ore-pickers and cobblers get 40 cents a day. Colored labor, of course, is used.

A prospect-shaft, 30 or 40 ft. deep, known as No. 5, has recently been sunk. It shows vein-matter, but no quartz or ore. If situated on the vein, it indicates a sharp twist at this point. The Thomas mine is apparently on the direct extension of the Holloway vein, though that vein has not been traced continuously to it.

2. The Yancey and Durgy mines lie 8 miles south of Virgilina, and are on the same vein. The Yancey is one of the oldest mines of the district, and was vigorously worked in 1892, when concentrating-works were erected. Two shafts, one 150 ft., and the other 88 ft. deep, were sunk, and some ore was extracted. The workings are now full of water, but the present owner, Mr. F. Durgy, expects to unwater the mine this year. The old Yancey shaft is large and well-timbered, and appears to be in good preservation. The old hoist is not covered, and the engine is now rusty. The former company erected in 1892 half a dozen cabins and a two-story house, and

a mill, about a quarter mile away. According to common report, the failure of this company was due, not to lack of good ore, but to bad management.

The dump shows the usual gray and purple schist, with white quartz and epidote. The ore is gray glance. The schists on the dump are much decomposed and altered by long exposure, the fragments having slacked down to a rather small size, with much soft micaceous débris. Some carbonate is still present, with a little gray copper-ore, spotted with bits of bornite.

Southward from the old Yancey shaft, the quartz-vein was followed along a very strong outcrop, on a gently rising slope, to another old shaft, where, however, no ore was found. The course is N. 3° to 5° E, and, according to Mr. Durgy, the vein has been traced over 1.5 miles S. of the Yancey shaft. It has been exposed also by a cut, a few feet south of the new opening made by Mr. Durgy.

A new shaft, now but 35 ft. deep, is being sunk a hundred yards south of the Yancey shaft. The rock extracted is purple and gray schist, with some quartz. The ore is mostly carbonates with scattering nuclei of glance and green-stained quartz. The rocks in the field near by are not schistose, but occur in angular blocks, 6 to 20 in. across, showing massive structure without schistosity, and look in part like epidote boulders, while they appear to be a volcanic breccia. The openings are much lower than the office and buildings constituting the old mining settlement.

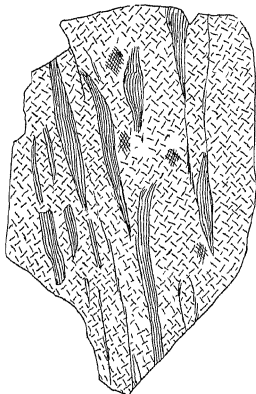
Shaft No. 1-64 is a new one alongside of an old pit, one-quarter of a mile N.E. of the Yancey. The foot-wall is a rather massive epidote rock; the hanging-, a fissile gray mica schist, resembling that common to all the veins. The ore-shoot is crossed by the shaft, and does not appear in the bottom. It is about 15 in. wide, the gray glance occurring in white quartz with some impregnated schist. The vein is composed of white "filling-quartz", but is in part a breccia.

The shaft is 74 ft. deep, with a drift 10 ft. to the south, at the bottom. Ore and epidote seem to replace square and angular fragments imbedded in white quartz. A well-defined streak of ore, 2 in. wide, also occurs. In other masses, the

glance appears in branches of mossy aggregates, which penetrate white quartz, or is found in threads in the altered schist.

3. The Copper World was first opened in 1882. The present owner, Col. Striff, has sunk a shaft 60 ft. deep, with drifts at 30 and 60 ft. It is equipped with a small steam-hoist, and is well-timbered. The vein shows the usual white quartz, with some epidote, encased in gray and purple schist. But one ore-shoot has been crossed, from which 8 to 10 tons of high-grade glance-ore have been stoped and shipped.

FIG 8



Specimen from the Thomas Mine, Virgilina, Va., Showing White Quartz Enclosing Shreds and Plates of Altered Schist (meta-andesite) This piece shows no ore. Scale, three-fourths of natural size

4. The Frazier mine is like the "native" shaft of the Eustis property. It shows no defined vein, but quartz-strings and ore-streakings in cracks and fissure-seams of a very massive epidote-rock. The ore is bornite. The absence of a vein is not a favorable indication, and search should be made for a quartz-body along the strike.

5. The Thomas mine, owned by the Whitney and Stevenson Co., of Pittsburgh, and opened by Mr. Henry Hyde, is supposed to be on the direct continuation of the Holloway vein, and

about one-half mile from it. The mine was not working at the time of my visit, and the ore-dump had been pretty thoroughly cleaned up. A few specimens were taken, however, to show its character. The gangue is white quartz, with included fragments of slate, which generally show a parallel banding, so that it is difficult to account for them as replacement-nuclei. Yet such fragments could not exist in open space, and hence the filling-quartz, which is clearly not replacement-quartz, must have been largely inserted between the schist-plates. The rock here clearly shows its former igneous origin, and is markedly porphyritic. It is an altered andesite (Fig. 8)

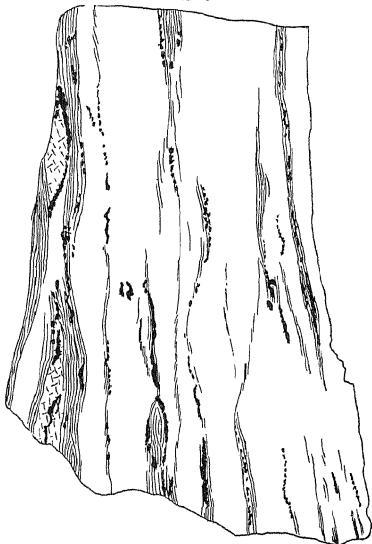
6. The Anaconda mine also belongs to the Eustis group. It is close by the road, in a field 1.5 miles north of Virgilina. The shaft is 5 by 7 ft. in width and 140 ft. deep. The ore is a mixture of glance and gray copper in quartz. The dump shows bright green schist, largely impregnated with epidote. Some seven car-loads have been shipped from this mine, which varied from 3 per cent. of copper in the first car-load to 12 per cent. in the last five car-loads shipped. The workings and stopes are limited in extent. There is some probability that the mine will be further developed; but the vein cannot be said to have received a very extensive trial, and the ore thus far extracted has come from but one shoot.

7. The Blue Wing mine is situated about three miles south of Virgilina, and on a different road from the Holloway. This mine has been known for at least ten years, and, under former management, was equipped with a crude plant for ore-dressing, consisting of a set of jigs and one Frue vanner. Judging from the tailings seen about the mine, and those hauled into town for macadamizing the streets, it is quite evident that much of the ore went into the tailings. The gangue is quartz and calcite, but no sizing was apparently attempted, so that the product of the vanner contained as much quartz as ore. At present the only attempt to dress the ore is by crushing and washing in California rockers, by which the concentrates are raised to 6 per cent. of copper.

The Blue Wing vein is an excellent example of a complex fissure-vein, in which the space between two fault-planes is closely sheeted, the rock occurring in thin, parallel plates, which are more or less torn apart. The ore occurs as a fill-

ing along narrow clefts between these broken sheets, and in part, also, as a minute impregnation of quartz-lenses in the altered rock itself. Definite evidence of metasomatic replacement has been obtained; but the bulk of the ore-body is quartz, filling open spaces. This structure is shown in Fig. 9. Where the vein crosses the diabase dike, the fracture-walls are dis-

FIG 9



Specimen of Blue Wing Ore, Showing Banded Structure. The white ground is calcite, with some quartz in little lenses. The solid black is bornite. The parallel lines represent schist. Scale, natural size.

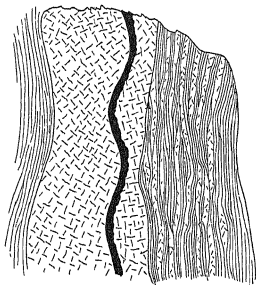
placed and the fissure becomes a shattered zone between fault-planes.

The shaft is now 180 ft. deep, with a 100-ft. and a 150-ft. level. The 100-ft. level, which runs 348 ft. north of the shaft, and about 115 ft. south, shows a vein of very constant width. In fact, from the surface down to the 100 ft. level, it is about

3 ft. wide, and shows well-defined foot- and hanging-walls. The ground has been stoped out within the last two or three years, so that no ore is now known above the 100-ft. level.

Fig. 10 shows the face at the north end of the 100-ft. level,

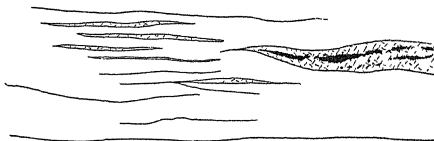
FIG 10



Blue Wing Vein, Face of 100-ft Level, North. On the right, gray slate with droppers and plates of white quartz. In the center, white calcite, with some quartz, and a streak of bornite. On the left, calcite and quartz, then slate.

Fig. 11, the roof above the stope, a short distance south of the face. Fig. 12, a sketch of the south face of the same level, shows quartz-lenses holding ore, and the slate-casing to the ore-lenses. This south face shows on the hanging-wall barren

FIG. 11



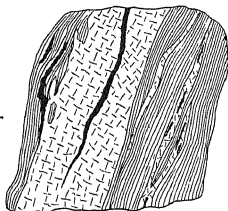
Blue Wing Vein, in Roof over Stope, above the 100 ft. Level, 350 ft. South of Shaft. On the left, calcite and a little white quartz, with dark streaks of slaty matter and spots of ore. On the right, ore in dark quartz.

white quartz and calcite, and on the foot dark gray sulphide slate with quartz streaks, holding parallel threads or films of what looks like slate dotted with ore. Ore (harder and darker in color) also occurs in the casing. The ore-body often presents a streaked or ribboned appearance, due, not to crustification or

to recent movement of the vein, but to partly-replaced sheets of slate.

In the 100-ft. level a dike 12 ft wide cuts across the schists and apparently cuts off the vein. This dike is followed continuously down to the 150-ft level, and there is seen to be crossed by the vein, which is not well defined, and consists of a mass of breccia cemented by calcite and quartz. At this level also the dike shows unmistakable evidence of slicken-sides and shearing by the vein. So far as could be made out, there is no very great decomposition of the dike-rock, but it simply carries the vein because the rock is very hard and resistant. No definite flutings were recognized in this property,

FIG 12



Blue Wing Vein, at the South Face of the 100-ft. Level. On the right, slate, carrying streaks of quartz. In the middle, barren quartz and calcite, with ore-streak in the center. On the left, schist, containing quartz lenses and ore—the latter both in independent streaks and in the casing of the lenses, for $\frac{1}{4}$ to 2 in from the quartz.

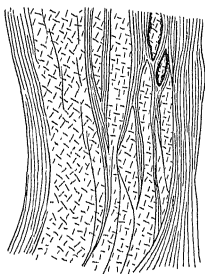
such as were seen in the Holloway. Much of the vein-matter shows included fragments of schist, sometimes angular, but more often in thin slaty masses. Following down the stopes to the 150-ft. level a continuous vein-section is seen, but, inasmuch as the stopes have been exhausted of workable ore, only the barren gangue shows in the remaining vein. The shaft was filled with water at the time of my visit, so that only the north level was accessible. The face shows a remarkably good example of the streaked or banded structure of these veins, the contrast between the white calcite and the dark schist being especially well marked. Specimens were taken of the dark schist impregnated with ore, to show the metasomasis that is supposed to have formed the ore at this place.

8. The High Hill mine, belonging to a syndicate of which Judge Graham, of Oxford, and Mr. W. T. Harris, of Virgilina, are the best-known members, is the only property at the north end of the district on which extensive development has been made. These gentlemen own about 1300 acres of land north of Virgilina and several hundred acres south of Virgilina.

The High Hill property is regarded as the most promising of the group. It is nine miles north of Virgilina, and extends from the banks of the Hyeo river southward to the cross-roads leading from South Boston. The tract is the highest in the district, being at the cross-roads 276 ft. above the Hyeo river, a tributary of the Dan. The vein is clearly traceable from a point only a few yards from the river's bank for a distance south of more than a mile. I walked over the entire distance, and found very generally a quartz outcrop, rising from a few inches to 3 feet above the surface, and from 2 or 3 to 12 or 15 ft. in width. In a few places it is broken down, and can only be recognized by a scattered drift. It is remarkably persistent in direction, showing no turnings, and has been opened by 13 shafts and pits, every one of which shows ore. At every outcrop, a few strokes of the hammer will show carbonate-stains, and at one or two of the pits gray copper is found at the surface. The quartz reef itself is an opaque white quartz, which looks very unpromising and barren, though, as just stated, it contains carbonate streaks and films wherever broken open. The only place where the adjacent schists have been exposed is at the No. 7 shaft, where a pit 20 ft. deep and about 20 ft. west of the shaft shows schists impregnated with copper and bornite. Throughout most of the property the outcrop is from 125 to 166 ft. above the river. The seven most northerly shafts are well timbered, and expose the vein at depths of 55 to 140 ft. This work was done by a syndicate of Boston wool-merchants and capitalists, who expended a considerable sum in prospecting, but gave up the property, whereupon the original owners took up the enterprise. They are sinking a shaft (No. 4) 140 ft. deep with a level at 60 ft. running 108 ft. north and 15 ft. south, from which a stope 31 ft. long and 16 ft. high has been raised. At 96 ft. a level has been run 15 ft. south. Ore consisting of gray copper with bornite in spots, was seen in the bottom of the shaft and at the level.

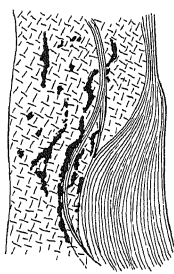
Fig. 13 represents the structure of the north face of the 60-ft level. Fig. 14 shows the north end of the shaft at the bottom. The ore-shoot is said to occur along the foot-wall, and it is commonly believed to have a southerly pitch. The ore carries traces of both gold and silver, and that found at shafts Nos. 1 and 2 is said to average 33 per cent in copper. From casual inspection of the ore exposed on the outside, I should think it fully as rich as that. Its character is the same in all the shafts, except, of course, that in the shallow pits only the oxidized ores are seen. The bornite decomposes along cracks and films to malachite, and in the ore stacked about shafts

FIG. 13



High Hill Vein, at Shaft No. 4, North Face of 60-ft. Level. Vein 8 to 9 ft. wide. Soft, fissile mica schist on the right.

FIG. 14



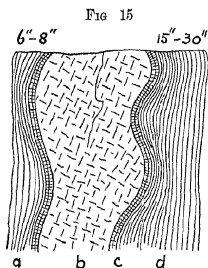
High Hill Vein, North Face at Bottom of Shaft No. 4, Jan. 28, 1900. Vein 8 to 9 ft. wide. Ore shown in solid black.

Nos. 1 and 2 masses of bornite are seen altered to covellite and nests of specular iron-ore. Malachite is also abundant, and drusy quartz of secondary formation appears. The lenticular form of the ore-body is shown in the sketch already given, and also in Fig. 15, representing the wall of No. 9 shaft. Several car-loads have been shipped from the High Hill mines, but owing to the distance from the railroad and the expense of hauling (\$1.50 a ton), no recent shipments have been made.

The shafts nearest the Ilyco river are 107 ft. deep and are connected by a level 180 ft. long, which is continued 130 ft. further south—nearly to daylight—from the shaft. No. 8 shaft is 72 ft. deep and has a 9-ft. drift at bottom. Six car-

loads, aggregating 267,000 lbs of ore, have been shipped, and averaged about 15 per cent. copper. The richest car-load showed, on sampling, 27.83; the poorest, 7.6 per cent. The gold and silver values are variable. Occasional fair assays have been made, for instance, a sample from the stock-piles of first-class ore yielded 8.46 oz. silver and 0.22 oz. gold per ton; but the returns of the car-load shipments show but a few ounces of silver and an average of but .01 oz. gold.

9. The Dorothy mine, on the west ridge, has two shafts 100 and 60 ft. deep respectively, with levels at 25 and 100 ft. The



High Hill Vein, Virgilina, Va., Exposed in South Wall of Shaft No. 9. *a*, Decomposed schist; *b*, quartz; *c*, gray schist, altered and showing green copper-stains; *d*, reddish decomposed schist

ore is bornite and glance in quartz gangue. One car-load shipped and several on the dump. Force employed, 20 to 25 men.

II. THE GOLD HILL TYPE.

This type presents fissure-veins of auriferous quartz in metamorphic schists, usually parallel to the foliation of the schists, and hence carrying lenticular bodies of quartz, linked together by quartz stringers. The ore is chalcopyrite, with an admixture of pyrite.

A large number of copper-bearing ore-deposits of the South are gold-veins, which have been, and still are, worked for their gold-contents. In many of the gold-veins of North Carolina especially, the mines were opened, the oxide ores extracted and sulphides encountered at the water-line. At some places, these sulphides have been successfully worked as gold-ores. More

often the mine was abandoned when the sulphides were encountered, especially if the ore contained an admixture of copper pyrites which prevented successful amalgamation. In many of the mines the sulphide-ores were found to contain from 2 to 5 per cent. of copper, present as chalcopyrite. A few properties of this kind are now successfully worked for copper, their auriferous contents being, in most cases, sufficient to give them an additional value. The Gold Hill mines are of this nature, and as they are now being extensively opened and exploited, they have been taken as a type of the auriferous chalcopyrite-veins of the South.

The Gold Hill Mine

Location.—Gold Hill is 14 miles southeast of Salisbury, on the Piedmont plateau. The country shows a relief of 200 to 300 feet, broad stream-levels separating flat-topped ridges, steeply trenched by lateral drainages. The Gold Hill district was formerly densely wooded, but has now been largely denuded about the mines and in the vicinity of the few farms which dot the region. The veins occur on a narrow plateau-ridge running N.E. and S.W., which is about $1\frac{1}{2}$ miles long and $\frac{3}{4}$ of a mile wide, the region being bounded by Buffalo Creek on the west. The veins are in an area of metamorphic schist, mostly argillaceous, bounded by an intrusive mass of granite on the west and by metamorphosed dioritic rocks on the east. The schists shows a foliation of N. 30° E. and dip 75° to 80° W. The veins have been proved to a depth of 800 feet, and have been traced on the surface for more than three-fourths of a mile. But their outcrops are obscure, and the continuity of the veins has not as yet been established beyond doubt. The ore occurs primarily in quartz; but small amounts are found disseminated through the altered schists.

History.—In a report by the State Geological Survey upon the gold-mines of the State, those of Gold Hill are fully described. It is said that these mines were discovered in 1842, which was comparatively late in the history of gold mining in the State. They were worked until 1856, yielding in 14 years over \$2,000,000 in gold. The sulphides were then encountered, and from that time until 1874 about a million dollars were extracted, but as the process of simple amalgamation extracted only 20 to 30 per cent. of the value, the ores were re-

garded as unfavorable. Gold-mining was practically stopped in 1893, and from that time until 1899 no mining was done. The treatment, up to 1881, was with Chilian mills and rockers. At that time a 20-stamp mill was put in. An attempt at cyanide-extraction was made in 1893, but without success. At the Isenhour mine, nearby, the ore is pulverized in a Howland crusher and concentrated on blankets, and the concentrates are washed in log-rockers with quicksilver.

The gold-product of this district came from a number of veins, but the main producers were the Randolph and Barnard mines, now owned by Mr. W. G. Newman. The former has a shaft 800 ft. deep, and has been practically worked out down to the 500-ft. level. As developed in mining operations, the values occurred in shoots, and one of these proved too rich in copper to pay for working by amalgamation as a gold-ore; so that this body has never been stoped. The mine is now being unwatered and, if the reports of the value of this copper-shoot be true, it will soon become a producer of auriferous copper-ores. During the active exploration of the district, a number of shafts 100 to 200 ft. deep and a great many shallower pits were made for the extraction of the oxidized free-gold ores. The Union Copper Co.'s tract was explored in this way, and a deep open-cut was made on a zone of mineralized and oxidized schist (locally slate) which carried gold. At 25 to 30 ft., copper was encountered; and the vein received the name of the Big Cut Copper vein, as which it is mentioned in various official reports. At present, the main ore-supply of the Union Copper Co. comes from two shafts on this vein, though nine other shafts on different parts of the property are being worked, one of which, that on the Munnicut vein, has yielded considerable ore, while another, a little off the belt of mineralized slates, yields argentiferous galena.

Surface Improvements.—Early in 1899 the various properties which had been idle for many years past were acquired by Mr. Newman, and in the past year a complete transformation has occurred. The timber has been cleared away; roads have been built; a 6-mile branch of the Southern railway has been extended to the property; old shafts have been cleaned out and retimbered and new ones sunk; and to-day there are eleven well-equipped shafts, and a complete plant, embracing:

"A large dam constructed to furnish water for concentration and other purposes, and between 100 and 200 buildings erected on the 1100 acres controlled by the company. Of these buildings, there are, perhaps, 100 dwelling-houses for the workmen, a three-story hotel, with 50 rooms, steam-heated, stables, offices, an assay-laboratory and a complete electric-lighting plant, furnishing light for the buildings, roads, shaft-houses and underground workings. Also, powerhouse containing ample boiler-power, large duplex air-compressors, a saw-mill, a blacksmith shop, a machine-shop with some 40 by 70 ft. of floor-space, and well equipped with lathes, pipe-cutting and all necessary tools and machinery.

"In addition to the large pond, covering several acres of ground, there are a number of small ponds upon the streams which flow into the creek from the eastward. There are 12 or 14 shaft-houses, upon as many old or new shafts, now being simultaneously sunk, and the outlook from the porch of the office-building on the summit of the hills reminds one of a large and prosperous Western mining camp. These shaft-houses are all well equipped with power- and hoisting-engines, and the shafts are well-timbered and have excellent ladder-ways.

"The most important building, perhaps, is the large concentrator, now practically completed on the plans of Earle C. Bacon, of New York City, and placed immediately beside the railroad-track, so that fuel and ore can be run directly into the building from the cars, and concentrates or other products shipped out. The building is constructed entirely of oak, which timber exists in unlimited quantities in this part of North Carolina, and stacks of almost any length and size are delivered at a ridiculously low price.

"There is probably no better-built concentrator anywhere, so far as the building is concerned. It is located at a point where the ore from the most important shafts, which are all on a higher level, can be run by gravity to the mill. From the dump it will be carried by self-emptying steel skips up an incline, the power being furnished by a double-cylinder reversible engine. One skip will ascend with a load, dumping automatically at the top, while the empty one descends. The ore passes through a chute into a 30 by 13 in. Farrel crusher, having a capacity of 400 tons per day of 24 hours. From the crusher the ore passes to a sorting- or picking-table, where the No. 1 copper-ore will be sorted out, as its concentration will be unnecessary. Barren slate will also be removed at this point. The second grade remaining on the table will pass through revolving screens, the coarse portion going to two 20 by 6 in. crushers, and then to two rolls, the fine from the screens going direct to the same rolls, which are 30 by 15 in. in size. The ore from the rolls is carried by belt-elevators with steel buckets into four sizing-screens; the coarse portion returns to the crushers, the fine portion, after passing six hydraulic classifiers, will pass to 12 Wilfley tables, there being one sizer for each pair of tables. From the tables the slimes or tailings will pass to buddles. In little things, as well as in the larger points, no money has been spared. For instance, the bearings are all adjustable and self-oiling, the shafting is of steel; the pulleys are of the split pattern; all belting is of five-ply rubber, except the driving-belt, which is of leather.

"The plant is driven by a Corliss engine, 18 by 22 in. cylinder, two 100 H. P. boilers furnish the steam. The concentrating-tables, it may be said, are run by an independent engine. The plant is lighted throughout by electricity."*

* "The Union Copper Mines, Gold Hill, N. C.," by Dr. A. R. Ledoux. *Eng. and Min. Jour.*, Feb. 10, 1900, p. 167.

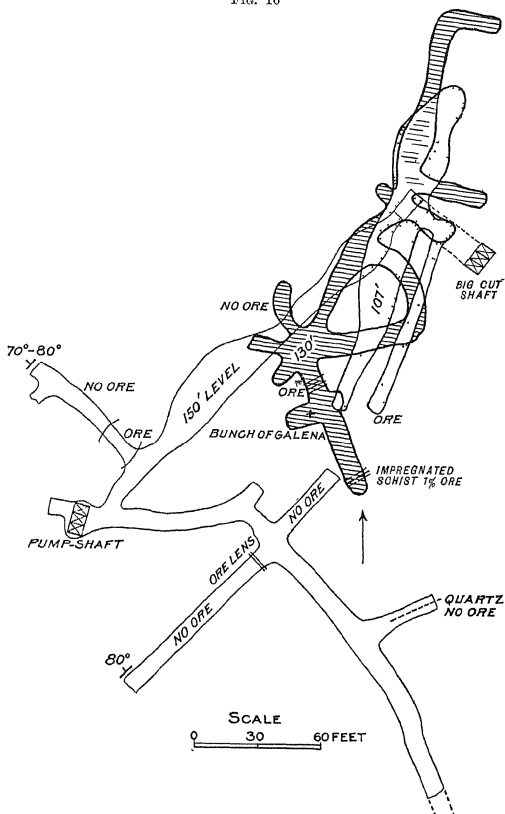
The Rocks.—The rocks of the region are greatly decomposed, and, except where exposed in the banks of ravines, have weathered to reddish-white or rusty slaty débris. The fresh material from the mine-workings is, however, gray or blue in color, and varies from a very dense and hard siliceous gneiss to soft talcose material. Under the microscope the rock shows a mixture of quartz and biotite with some hornblende. The quartz is very finely granular, but holds veinlets and spots of coarser grain. There is much pyrite, usually associated with the green hornblende.

Vein-Phenomena.—A mineralized belt extends along the edge of the hill, from the mines seen in the village of Gold Hill, beyond the Union Copper Co's workings, in a direction generally parallel to the schistosity of the rock. There are lesser veins, recognizable in part by outcrops and in part by old prospect-pits, which run across the banding of the schist and end in the belt mentioned. As a rule, the so-called gold-veins are recognizable only by the greater amount of iron staining the weathered rocks; and the few visible outcrops of quartz are barren of value and do not form well-marked veins. That the veins of the district are true fissure-veins and continue in length and dip, is clearly proved, however, by the workings of the Barnard and Randolph mines nearby.

The exact nature of the copper-deposits and their relation to the schists have not been conclusively determined. So far as the writer was able to observe, the ore-shoots conform in dip and strike to the secondary schists, and pitch to the north. They show no banding. Composed largely of a distinctly and finely granular dark-gray quartz, with patches, spots and streaks of ore, they present little or no crystalline or massive white or transparent quartz, such as is commonly seen in quartz-veins, and is usual in the auriferous "stringer-lodes" of the South. A large part of the ore-shoot consists of a breccia of fragments of hard, white, silicified schist, enclosed in quartz-ore, showing conclusively that the slates were shattered and breccia-zones were formed before the ore-bearing solutions became active.

The ore-bodies show no well-defined walls, clay-slips or seams. They have, however, been fractured by later movements, as is shown by vertical fractures which serve as conduits for de-

FIG. 16



Plan of the Mine. Workings of the Union Copper Co., Big Cut Vein, Gold Hill, N. C.

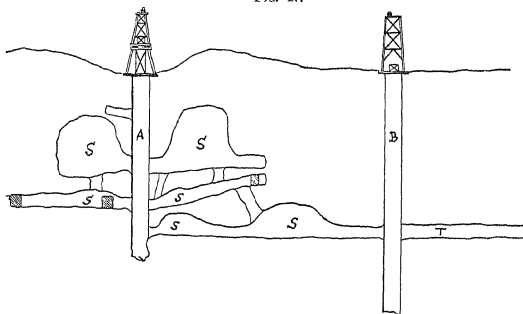
scending waters, and by subordinate flat fractures connected with the first, and believed to be due to the strains result-
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ing from the formation of the first fissures. These flat fissures dip south at 20° from the horizontal.

The occurrence of the ore-shoot of the Big Cut or Union vein is apparent from the plan of the mine-workings, Fig. 16, redrawn from the illustrations of Dr. Ledoux's paper, and from their vertical projection, Fig. 17. The irregular workings are the result of an inadequate comprehension of the nature of the deposit during the early development of the property.

The only ore-shoot exposed at the time the property was visited (Dec., 1899), showed a length of about 150 ft., and

FIG. 17.



Projection on a Vertical Section-Plane of the Workings of the Union Copper Mines, Gold Hill, N. C., from the Big Cut Shaft to the Pump-Shaft. After Dr. A. B. Ledoux. Scale, approximately 100 ft. = 1 in. A, Big Cut shaft; B, pump-shaft, S, S, stopes; T, tunnel south towards the Townsend shaft.

a width of 20 ft., and extended from the upper level to the deepest workings. Average samples taken by Dr. Ledoux showed the following values: Ore from the 130-ft. level, 4.42 per cent. copper, 3 oz silver, 0.20 oz. gold; and for a width of 25 ft. across the shoot on the 155-ft. level, 3.70 per cent. copper, and a trace of gold.

During the six months preceding Jan. 1, 1900, nearly 50 car-loads of 30,000 pounds each were shipped. The ore was hand-sorted, and carried between 10 and 15 per cent. of copper. The ore needs concentration, however, and upon the successful working of the mill depends the future success of the property.

As already observed, the company is working and sinking eleven shafts, nine of which were visited. At only four shafts had any copper-ore been encountered. The Big Cut shaft was 221 ft. deep on the incline (195 vertical), and the Pump shaft, 213 ft. distant, more than 200 ft. vertical. The shafts are all large, well-timbered, and show but little water.

Character of the Ore.—The ore below water-level consists of pyrite, chalcopyrite and quartz, with occasional bunches of galena and blende. The pyrite is in broken shattered masses, in part cemented by chalcopyrite, which is distinctly later in origin, and surrounded by quartz of coarser grain than the main mass of the ore. The extreme upper part of the vein is leached and barren of copper, but has been worked for its gold. Below this rusty weathered zone, the vein shows marked alteration; the quartz and schist are dull, shattered and rust-stained, and carry blue and green carbonates, cuprite and native copper—the oxide often in beautiful crystals. Below this, the ore-body shows opaque white quartz of a sugary or flour-like texture, carrying sooty black sulphide of copper, and passing into the oxidized ore where pipes and water channels extend down into it. This partially altered ore contains crystallized and massively crystalline and dull chalcocite; and nucleal masses of copper pyrites may be seen, surrounded by all the alteration-products mentioned. The alteration takes place especially along the vertical fractures, and those dipping at 20° which connect with the verticals. In general, the vertical fissures are marked by oxidized material, leached of copper, even down to the 150-ft. level—which fact leads to their designation as gold-veins. The flat-dipping fractures usually show red oxide and sheets of native copper. While there is no sharply defined limit to the zone of enrichment, the ore-shoot is markedly enriched for from 15 to 20 ft. above the sulphide-ore.

Origin of the Ore.—The ores show no banding or crustification, but do exhibit a brecciated structure. The quartz is not massive; and the ore-bearing quartz has not the characters of quartz filling an open cavity. On the contrary, a study of the occurrence of the ore in the mine, and of specimens, indicates a replacement of schist by quartz, or a replacement of the ferromagnesian mineral by ore. The study of thin sections shows that a mass of silicified schist, holding pyrite, has been shattered

by fault-movement, and chalcopyrite, together with a little galena and blende, and a new growth of quartz have been deposited. The chalcopyrite has been altered in part to bornite, and to glance near the water-level, or to cuprite and malachite and azurite, when oxidation has been more pronounced.

Notes on the Mine-Workings.—In the Hannicut shaft, which is 120 ft. deep, on a gold-vein parallel to the first, the ore is similar in character. A few car-loads have been shipped from this vein, but the shaft shows slaty rocks dipping at 80° , and no very well-defined ore body was seen at the bottom. The west wall is schist, cut by planes dipping 30° N., and corresponding in appearance to those cutting the quartz-pyrite ore of the Big Cut vein. A little quartz with calcite was noticed in the bottom of the shaft, where the schists forming the walls are very soft and leafy. A cross-cut 10 ft. above the bottom of the shaft runs 8 feet east, and shows from $3\frac{1}{2}$ to 4 feet of good calcite-ore, very plainly defined by a thin $\frac{1}{2}$ in. to 1 in. seam of soft clay gouge on the foot-wall and by a schist hanging-wall. Another level, 60 ft. in depth, shows a lense of calcite-ore with bornite which is said to appear both sides of the shaft. The rocks here are soft and hard gray sericite-schists, in part impregnated with pyrite, but showing chalcopyrite only where the schists are replaced by quartz in spots or strings.

Eight other shafts have been sunk upon the property to depths of from 100 to 175 ft., but up to the present time the three mentioned, together with the Silver shaft, are the only ones which have yielded any ore. A concentrating-plant with 10 Wilfley tables is now being erected, and excavations were being made for a smelter at the time of my visit. The future of the property is as yet somewhat problematical, as many of the shafts are being sunk on untried veins, in which ore-bodies have not yet been struck. It is quite safe to assume, however, from experience in the neighboring Randolph and Barnard mines, from which the gold of the district was produced, that large bodies of chalcopyrite ore exist, and that the percentage of copper is high enough to pay for extraction if the work is carried on in an economical manner. No visit was made to the old Randolph mine, as the property was full of water and would not be pumped out for some weeks. This is the mine which is sunk to the depth of 800 ft., and which carries ore in well-defined

shoots, one of which was too rich in copper to pay for working when the property was operated as a gold-mine.

The Silver mine, which is situated somewhat to the east of the other veins, was worked for a number of years on account of the large mass of galena found there. The rocks are sericite-schists, very soft and greasy in feel and appearance; and the ore is a galena, usually fine-grained, often occurring as an impregnation of schists, and found in lenticular masses parallel to the schistosity. No well-defined vein was recognizable, nor is there any well-defined wall. The gangue is barite, calcite and hydrous micas, one of which is bright green in color. Several car-loads have been shipped from this property, but the workings visited cannot be said to offer a definite assurance of a large output in the future.

Other Deposits of the Gold Hill Type.

In Bulletin No. 3 of the *North Carolina Geological Survey*, a description is given of a number of auriferous veins of the Gold Hill type. Many of these mines, which have in the past been worked as gold-mines, and are so described in the report, have shipped more or less copper-ore, and, at the present price of copper, may be opened as copper-mines. Perhaps the best known is Copper Knob, in Ashe county, North Carolina. This mine has been worked at various times as a copper mine, but is now closed. The shaft is 140 feet deep, and shows chalcopryite and pyrite in a quartz gangue.*

The Conrad Hill mine, 6 miles east of Lexington, shows quartz-veins in fine-grained, thinly laminated, argillaceous schists striking N. 10° to 20° E, and dipping 80° to 90° N. W. The ore is a chalcopryite in quartz, and carries some iron carbonates.†

Salisbury is the center for a considerable number of gold-mines lying from 6 to 20 miles distant. A number of these contain large amounts of chalcopryite, as, for instance, that of Gold Knob, 9 miles, Dutch Creek, 10 miles, the Reimer, 6 miles southeast of Salisbury, on the Yadkin river, and the Bullion, one-half mile east of the Reimer. None of these properties

* Bulletin No. 3, *N. C. Geol. Sur.*, p. 180

† Bulletin No. 3, p. 52; also, "Ores of North Carolina," *Geol. Sur. of N. C.*, 1887, p. 214

have been worked in recent years, and up to the present time none of them have been opened as copper-deposits. From all that can be learned concerning their ores, they are likely to yield from 2 to 3 per cent. of copper.

Near Jamestown, N. C., there are other idle properties which have yielded in the past more or less copper, although currently reported as gold-mines. The Gardner Hill mine is 2 to 3 miles north of east of Jamestown. It is a true vein, running N. 20° E. with a westerly dip. The fissure is 3 ft. wide at the top, but tapers to 8 in. at 80 ft. in depth. It shows 6 to 12 in. of quartz in granite. There is much chalcopyrite present. When the copper-ore was first encountered no effort was made to extract the gold. For a long time 40 tons a week of yellow copper-ore, averaging 20 to 25 per cent. in copper, were shipped. There are five shafts, of which the deepest is vertical and 258 ft. deep. Three veins are known to exist on the property.*

The North State copper-mine is 2 miles west of south of Jamestown. The lode is from 4 to 8 ft. wide, and is traceable for 3 miles. It was worked in 1883 to a depth of 325 feet.

III. THE DUCKTOWN TYPE

The third type of deposit comprises the pyrrhotite veins found at various localities along a belt in the Alleghanies from Alabama to Virginia, and of which instances occur in Vermont and Canada. The best known locality, and the one most thoroughly explored and studied, is Ducktown, Tennessee, for which reason this very distinctive class of deposits is called the Ducktown type. The deposits occur in fissure-veins in metamorphic schists, the fissures running nearly parallel to the schistosity. The rocks are of sedimentary origin, as shown by field-study and microscopic slides, but all ordinary characters of sedimentary rocks are gone. At every locality the veins are distinguished by great caps of limonite gossan, now utilized as a valuable iron-ore. Beneath this is, or rather was, the zone of the black sulphide-ores now exhausted, while the unaltered vein-matter consists of pyrrhotite, carrying spots and patches of chalcopyrite with more or less pyrite, the latter mineral becoming so abundant in some veins as to predominate.

* See also Emmons's Report, "Geology of Midland County, North Carolina," pp. 174-6

These deposits are enclosed in schistose or slaty rocks, which, though similar in superficial appearance at the various localities, are of very different character and origin. They have long been regarded by many writers as examples of bedded deposits, since they often show a lenticular shape and are usually conformable to the foliation of the rocks. There is, however, good proof that many of the deposits are along lines of dislocation and may be regarded as true fissure-veins, probably of replacement-type. The ore-bodies whose neighboring outcrops form the "great gossan lead" of southwest Virginia, are of this class, as are the Ore Knob and Elk Knob deposits of the mountain region of western North Carolina, and Stone Hill, Alabama. Their distribution is shown upon the accompanying map (Fig. 1, p. 451).

The Ducktown Mines.

The Ducktown district is situated in the extreme southeastern corner of Tennessee, in an open basin enclosed by bounding mountains on the east and west, the Ocoee River on the south, and a broad plateau-level on the north. The ore-deposits occur in a belt about 2 miles wide and 4 long, their general distribution being indicated upon the accompanying map. The rocks are gneisses and schists, usually weathering readily, so that outcrops are rare, and disintegration commonly extends to a depth of 50 to 90 feet. In the best exposures the prevailing rocks are micaceous and very finely puckered. They are of sedimentary origin, as determined by field relations and by an examination of slides by Prof. Kemp. They are regarded by Keith and Campbell as the lower part of the Ocoee series of pre-Cambrian age. The schists have throughout the district a very uniform strike of N. 20° to 25° E., and dip 50° to 55° E. The original bedding-planes are supposed to conform to the schistosity. The ore-bodies occur in veins nearly parallel to the foliation of the rocks. There is a difference in dip; and the writer has observed the vein-outcrop crossing the schists at the Blue Ridge property. There has been secondary fracturing and faulting of the veins since their formation; and the lenticular form of the deposits is ascribed by Henrich* to these

* Trans., xxv., 173

faults. The veins vary from a few feet to 150 feet in width, showing a solid mass of ore for the entire distance. They can commonly be traced for distances of a mile by surface-outcrops; and the most northeasterly vein, the Burra Burra, has been followed by black-copper workings for two miles. The observations of Henrich upon the structure and the records of the diamond-drill borings agree with the observations of Kemp and of the writer that the deposits fill fissure-veins.

The different ore-bodies differ considerably in character. That of the Isabella mine is so pyritous that it has not been worked for copper since the extraction of the secondary black-copper ores lying along the water-level. The Burra Burra and London veins have less pyrite than the Isabella and a larger amount of chalcopyrite and pyrrhotite, while the Mary-Polk County ore is pyrrhotite with little pyrite. The copper-content is greater in the pyrrhotite ores, and in a general way may be said to be proportioned to the amount of pyrrhotite of the ore-body as a whole. It will average $3\frac{1}{2}$ per cent. in the ore as it goes to the roast-heaps, varying in the mine from about 1 per cent. to 6 or even 10 per cent. in occasional bunches. The copper-value lies in the chalcopyrite, scattered through the pyrrhotite in small grains and films, and more rarely occurring in bunches.

The vein shows a notable lack of quartz, and consists essentially of iron sulphide for the entire width of 20 to 100 feet. Although the ore-body is said to be pyrrhotite, it varies in purity and value, and is not always workable. This is in part due to the larger proportion of the accessory minerals in the ore, or simply to a lower percentage of copper. More or less quartz in clear, rounded grains, tremolite, etc., occurs in what appears to be solid pyrrhotite; and in the leaner ore these increase in amount. Bunches of white quartz several feet across are sometimes encountered in the main mass of ore, while layers of slaty ore are found parallel to the walls. Hornblende ore—a mass of interlaced hornblende crystals with the open spaces between filled by sulphides—often appears along the walls.

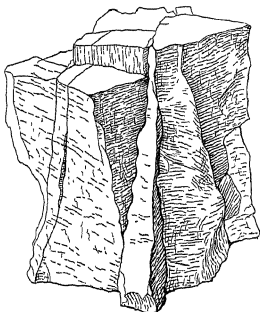
The structural characters of these ore-bodies show that they fill fault-fissures, which follow the foliation, and correspond to slip-planes between the "beds." This movement probably

furnished a channel for waters which attacked and replaced the more or less lenticular masses due to a regional metamorphism of an original calcareous shale.

This was largely altered to a mass of tremolite, zoisite, garnet, etc., such as is commonly observed as an alteration-product of impure limestones where such rocks have been metamorphosed. These lenses, shattered by the fault that preceded the formation of the ore-body, were attacked by circulating waters, and the non-soluble constituents were dissolved away and replaced with pyrrhotite, etc.

This supposes an original swelling out and contraction of the

FIG 18



Films of Native Copper and Cuprite in Fracture-Seams in Greenstone (Meta-Basalt or Catoclin Schist)

ore-bodies, a sort of lenticular structure. This has been modified by faults since the formation of the vein, to which faults, in part at least, the present lenticular forms of the ore-bodies so far worked are due. The ore-body is thrown by these faults, and it is to these movements that the ore probably owes its somewhat schistose structure, and not to original replacement. The flat fractures which part the ore, and are in some places marked by films of calcite or quartz (later than the ore), are believed to be strain-cracks such as would form between two parallel shears.

The following detail-notes were made during a reconnais-

sance-visit to the Ducktown district in December, 1899. The English company, "The Ducktown Sulphur, Copper and Iron Co.," is operating the Mary mine and the Calloway shaft, the latter being merely a prospecting work, not now shipping any ore. The Tennessee Copper Co., which owns all the claims not owned by the Ducktown Co., is operating the Polk County mine, preparing ore-reserves to be used when a smelter is operated, and putting down new shafts at the London and the Burra Burra properties. The same company controls the old Tennessee mine, which is not, however, being worked. In the London and Burra Burra properties, the new shafts are being sunk at an incline of 75° , following down a band of gneiss parallel to the ore-body, and 100 ft. back in the foot-wall. At 100 ft. below the gossan, the first cross-cut will be driven to the vein. The only deep workings now accessible are those of the Polk County and Mary mines, which adjoin one another in the same vein. The Isabella mine is shut down and the Tennessee is flooded. The Tennessee Co. is said to be making arrangements to treat a daily output of 1000 tons of ore; the Ducktown Co. is now smelting 300 tons of roasted ore per day. The situation, geographic and topographic features of the district and its history are fully treated in the paper by Mr. Henrich, from which the foregoing account has been largely drawn, and which presents many geological observations and a full account of the metallurgical treatment at the Isabella property in 1895. The treatment at the present time is practically the same as that described by him, and the development-work in the mines is no further advanced than it was at the time his paper was written, save only that the stopes are very much larger, and large bodies of low-grade ore have been extracted which in former years were considered too lean for treatment. The deepest mine is the Mary, the bottom of the shaft being 350 ft. below the collar. The levels are driven at 10, 20, and 30 fathoms respectively, the basis of measurement being the top of the sulphide ore-body. The brief time devoted to the examination of the mines made it necessary to confine my examination to the observation of the more salient features of the region, and for this purpose Mr. Henrich's paper was taken as a text, and his observations were repeated

to determine whether the writer agreed with the explanations given by him. I shall, therefore, take up the different features in the order in which they are given in his paper.

The micaceous schists and gneisses of the region are unquestionably metamorphic in origin, and I am informed that both Arthur Keith and Prof Van Hise, who visited the region three years ago, found evidences that the rocks are part of the Ocoee series, though they form the older part of the formation, which has as yet received no name. They show evidences of faulting, the schists are intensely puckered and crumpled, and the district does not belong to the region in which the Appalachian folds have been described, as these foldings are only those of the later sedimentary rocks. Of the two faults supposed by Mr. Henrich to bound the basin on the east and west, I find no evidence whatever. Moreover, the careful work of Mr. Arthur Keith, of the U. S. Survey, shows that no such fault exists. For this reason I cannot believe that the ideal section given by Mr. Henrich represents anything more than a mere conjecture on his part. That the faulting in the vicinity of the ore-bodies is due to the sliding of gneiss and schist one upon another, seems to be borne out by my observations. The fault-fissures follow the foliation of the rocks, but there are also other faults which clearly cross the banding of the rocks. That the walls of the ore-deposit of the Mary lode are fault-planes is not, I think, entirely proved by the present exposures.

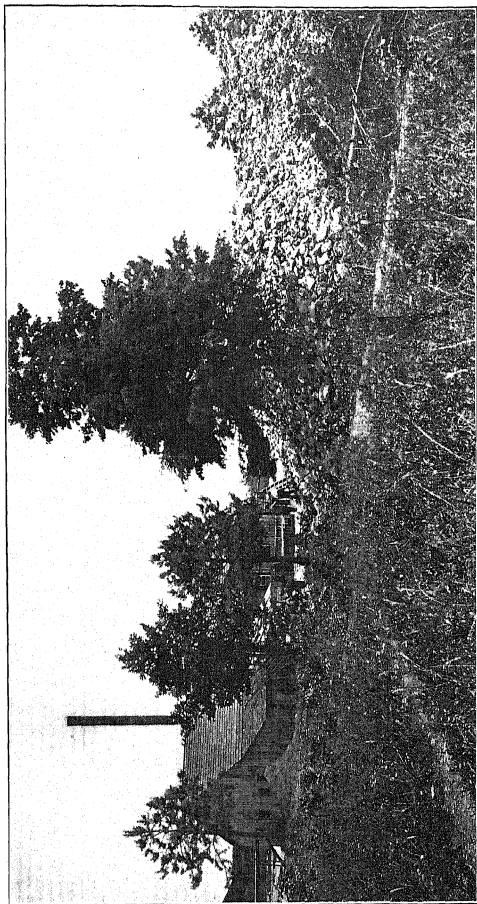
In the upper workings, both of this vein and that of the London property, the hanging- and the foot-walls are well exposed in the gossan-zone, and are clearly defined. In the Mary mine, however, there is a gradation from ore into country-rock which appears to be the result of a metasomatic replacement. That post-mineral faulting has occurred, however, in this ore-body is plainly to be seen by the slickenside surfaces; but such faulting is in general at an angle more or less acute to the true boundary-wall of the deposits. It should be noted, however, that in these workings the large bodies have been thrown, and the supposed walls are in part, at least, post-mineral faults. The so-called Ferguson level, along which Mr. Henrich made his observations, showing a banding of the schists close to the ore-body, indicating a fault, was not visited by

me, but all reports confirm the statement that the schists curve toward a fault-plane, which is believed, however, to be post-mineral in formation.

The large size of the ore-bodies makes a critical examination of the property very difficult. Chambers from 50 to 150 ft. across and from 25 to 150 ft. high are not timbered, and their walls are precipitous, without ladders. Even with the aid of magnesium-light, the details of structure were not clearly observed, owing to powder-smoke in the air. There is, however, a certain schistosity to the ore which is plainly apparent.

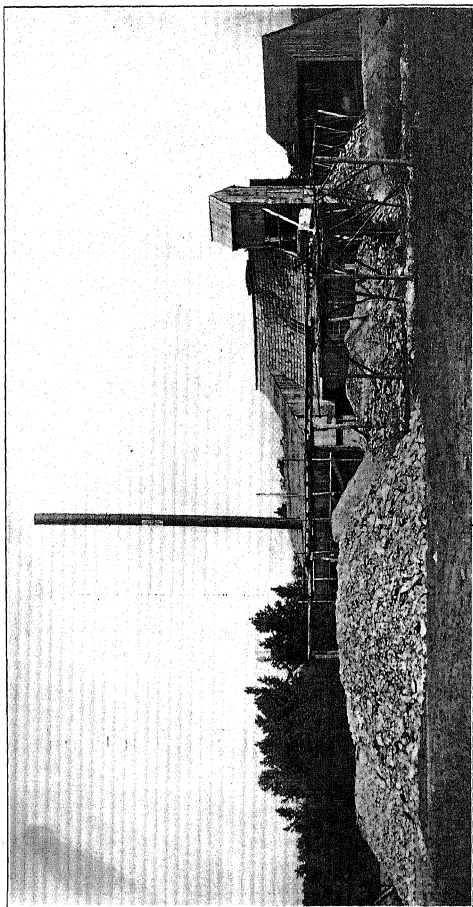
The flat-lying planes of which Mr. Henrich speaks, and which he believes to limit a downward circulation of surface-waters, are quite prominent, and are very well marked in mining, as the ore breaks to these planes. They are not constant in direction or in angle of dip. In the only instance in which they could be traced to an undoubted fault-fissure they curved into the fissure and seemed to be plainly part of the fault-movement itself, having been formed by the stress incident to the sliding of the mass of ore along the fault-plane—a phenomenon common, I believe, in other rocks. No clay gouge or fault-breccia or other evidence of faulting was observed along the bounding-walls of the deposit, except where post-mineral faulting had occurred; and in the latter instance such products of fault-action are not at all prominent. Large masses of quartz occur in different parts of the ore-body; and this quartz is usually white and not perfectly transparent. In the mass of the ore itself there is little if any hornblende (tremolite), and the ore consists essentially of pyrrhotite, with scattered and generally minute grains of chalcopyrite, and in some portions more or less pyrite. Horsts of included schist occur, and in such cases the rocks are thoroughly impregnated with the sulphides, and often show, near the contact, more or less hornblende. Garnet and calcite are common also about the borders of these included masses, and also at the borders of the main ore-body. The hornblende-ore itself is commonly taken out upon the borders of the ore-body, though in some instances the cleaner and richer ore carries a little hornblende scattered through it, as well as rounded masses of transparent quartz. The garnet and calcite are clearly gangue-minerals, and the ore occurs disseminated through them.

FIG. 19.



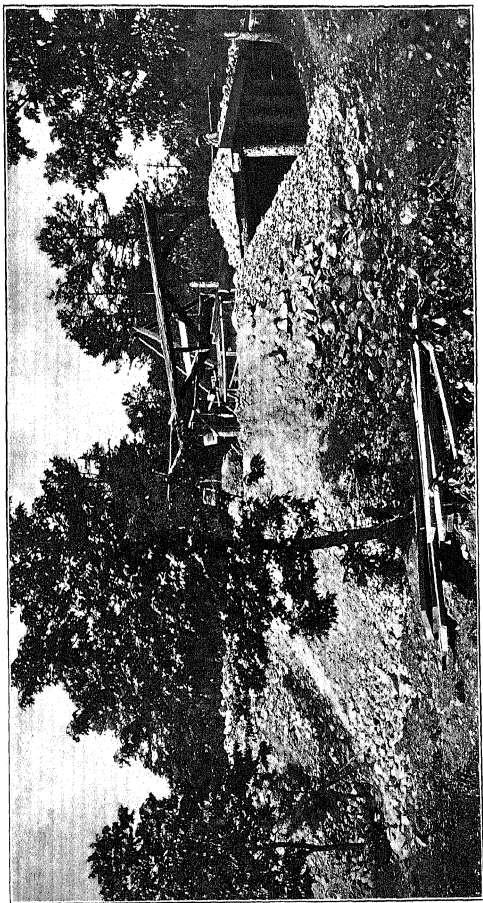
Holloway Mine, Person County, N. C.

FIG. 20.



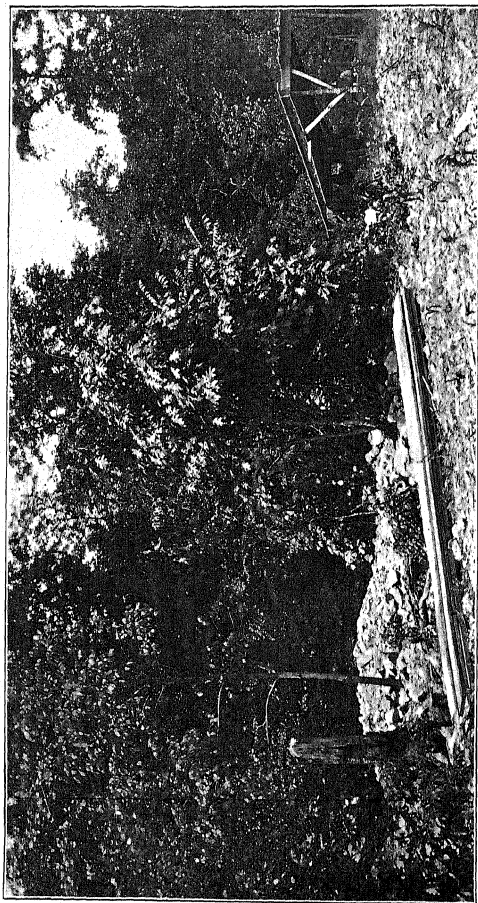
Blue Wing Mine, Granville County, N. C.

FIG. 21.



Thomas Mine, Person County, N. C.

FIG. 22.



High Hill Mine, Halifax County, Va.

The decomposition by surface agencies of both these ore-bodies and their enclosing rocks is very marked. The softer crystalline schists are decomposed to a depth of 50 to 60 ft., and the ore-bodies to a depth of 50 to 90 ft. The observations from which these data were obtained were made in the new shafts of the Tennessee Co and in old shafts which are still accessible. In this decomposition of the lode, the upper part of the ore-body is converted to a very pure red limonite, running from 50 to 60 per cent. in iron, and affording numerous masses of iron ore, one of which is now being mined at the Isabella property, 25 to 30 car-loads a day being extracted, all of which goes to Kentucky and Tennessee furnaces.

Beneath the gossan there is an irregular body of black copper-ore. The thickness of this black copper varies from a few inches to 8 ft or more. It is extremely irregular, has the consistency and color of ashes, is easily worked, and has been practically entirely extracted from all the ore-deposits of the neighborhood. A careful examination was made of the old black-copper workings of the London mine, in order to determine the character and extent of decomposition, and whether the secondary enrichment of metallic sulphides which had taken place in this district was similar to that of other localities. The material itself is extremely unpromising in appearance. It shows no clean mineral, and no recognizable copper glance is visible. The analysis made by Hermann Credner showed, however, that it consists in part of black oxide of copper and of copper-glance. The samples brought in by the writer are yet to be studied. In the black-copper zone the evidence of downcoming waters is unmistakable. The workings are still moist, and the waters are extremely acid, and are attacking everything within reach at the present time. The most notable decomposition is perhaps that observed of bunches of clear quartz which are being altered to a silky sericite-like mineral. The schists are leached and changed to white, lustrous micaceous masses, and the hornblende is altered to silky sericite.

According to Kemp,* solutions acid with sulphuric acid attack silicates such as feldspar and biotite, remove alumina or

* "Ore-Deposits of the U. S. and Can.," 1900, p 45

change it to kaolin (?), and cause the separation of free silica. That some such process is actually at work in the superficial alteration of the Ducktown ore, no one who has studied the lower part of the gossan can for a moment doubt. The downward-seeping waters, carrying iron and copper sulphates and acid with H_2SO_4 , are depositing small amounts of silica, and in one place noted by the writer are cementing the sand formed of grains of disintegrated quartz. It is difficult to understand the disintegration of the occasional masses of white, massive, coarsely-crystalline quartz of the ore-body. This is seen changed to a granular, loose-textured mass, with decided lamination or lining, this arrangement being possibly due to a shearing of the unaltered quartz, as we know the ore-body shows evidence of general shear. It is, however, difficult to explain the occurrence of quartz pitted and eaten into by the waters, and showing nests of feathery sericite (?).

The zone of decomposition is not limited by the flat planes, as supposed by Mr. Henrich, but follows in a general way a plane parallel to the contour of the hill, showing that it is simply the downward limit of surface-waters. The floor of the old black-copper workings is extremely irregular, and in general runs down along the foot- and hanging-walls of the pyrite-bodies, so that the black oxides were found at depths of 5 to 20 ft. below the top of the sulphide body along the walls of the deposit. The samples obtained showed residual kernels of the unaltered pyrite, with the usual black or sooty decomposition-products, so common where sulphides are altered by surface-waters. A careful search failed to show the presence of a floor of quartz lying between the black copper and the unaltered sulphides. Quartz was, it is true, found at several places, but only where it had clearly been brought down by the descending waters, or where it was the result of primary mineralization and had been simply left in the alteration of the deposit. Moreover, a very careful study of the many flat fissure-planes seen underground in the unaltered sulphides failed to show the constant presence of quartz. Where it was found, it was apparently of no greater significance than the occasional films of calcite seen along such planes. If, however, my hypothesis is correct that these flat planes were formed by post-mineral faulting, the occurrence of such minerals as calcite and quartz

is easily accounted for by the action of waters descending along the main fault-fracture and penetrating these flat-lying planes—a process which is undoubtedly now going on, as the only waters in the mine are those coming down such fault-planes. The mass of the ore-body is itself remarkably free from water, in fact, there are no vertical fissures or other water-channels to deeper levels, except the fault-planes just mentioned. It is not, I think, positively determined that there is no horizontal sheeting of either rocks or ore-deposit, limiting the surface-waters. No banding or crustification was observed in the ore-bodies; and the evidence seemed to show that they are replacement-deposits and not the filling of open cavities.

I could not obtain the diamond-drill records, which are naturally regarded as confidential. The English Co. has driven many of these holes; but they are seldom over 100 ft. in length and are driven at right angles to the workings from the stopes and levels of the Mary mine. The Tennessee Co. has driven some long holes into the hillsides and has thoroughly established the value of such ore-bodies as follow greater depths than any shown by the mine-workings.

In a paper by Sterry Hunt* published in 1873, describing the Ore Knob Copper mine, he gives also some notes upon the East Tennessee vein at Ducktown. He says that it is a fissure-vein, containing massive pyrrhotite and chalcopyrite, traversed by zoisite, idocrase, hornblende and pyroxene, the latter in crystals often an inch in diameter and 6 in long. The hornblende crystals are often curved and partially broken, and show transverse fissures filled with sulphides, which are also occasionally interposed between the cleavages of augite-crystals. The silicates are sometimes incrustated with chalcopyrite, galena, blende, and rarely with crystallized chalcopyrite. The country-rock is described as white cleavable augite; and a fibrous hornblende of white, green, or light brown tint is also mentioned. But Dr. Hunt's most important suggestion is that pyrrhotite will precipitate copper sulphide from copper sulphate. The black copper-ore he describes as consisting chiefly of sulphide, some-

* Ducktown, M. Tuomey, *A. J. Sci.*, 11, vol. xix, p. 181, 1855. J. D. Whitney, *A. J. Sci.*, 11, vol. xx., p. 53, 1855. Ansted, *Quar. Jour.*, vol. xii, p. 253. Sterry Hunt, 1873, *A. J. Sci.*, 11, vol. vi, p. 305, also *Trans.*, 11, 123. Carl Heinrich, *Thans.*, xxv, 173.

times with excess of iron, but more commonly with a large percentage of copper. It approaches copper-glance in composition. He says that crystals of glance have been observed by Mr. August Raht in druses in this ore. At times, the ore approaches bornite and chalcocite in composition. Some of the black copper-ore holds grains of copper and crystals of red oxide. It is commonly impregnated with copper sulphate, which drains off. As much as 5000 pounds a month of cement-copper have been obtained from the water, which contains about one-tenth of one per cent of copper.

In the last edition of Kemp's *Ore-Deposits of the United States and Canada*, the geological history of the Ducktown veins is stated as follows (p. 192)

"From observations on the succession and character of the minerals in the vein, J F Kemp has drawn the following conclusions regarding the geological history of the veins. By a process of regional metamorphism, a sedimental series of shales and sandstones was altered to mica schists and quartz schists. Where the ore is now found, zoisite, tremolite and garnet were also produced, but it is not known whether they are met outside of the mines or not. They indicate the former presence of magnesian and calcareous rocks, although, generally speaking, lime is practically unknown in the metamorphic rocks of the district, and the local waters are remarkably pure and soft. Whether a calcareous shale or an intruded dike yielded the lime silicates, or whether they are metamorphosed, calcareous, vein-material from an older vein-filling cannot be stated. After the general metamorphism, a series of dislocations was developed along the lines of the present veins, and pyrrhotite and sometimes pyrite were introduced. After the deposition of the pyrrhotite there was further movement, which shattered the pyrrhotite and allowed the introduction of chalcopyrite in streaks and fine veinlets all through it. Still later, and apparently after another movement, calcite came in and penetrated the shattered sulphides and older silicates. After the introduction of the calcite, by some movement fissures notably horizontal were produced, which became filled with glassy quartz, and which have yielded the so-called "floods". More or less contemporaneously with the quartz, coarsely crystalline pyrrhotite, chalcopyrite and blende were produced, which are in marked contrast with the earlier sulphides. The oxidation of the veins above the ground-water, the formation of the brown hematite outcrops and the development of the zone of enrichment (the black) bring the process down to the present."

Other Examples of the Ducktown Type.

Alabama Mines.—In northern Alabama deposits in every way analogous to those of Ducktown have been known. The so-called "copper lead" of this State is a strip or area of altered igneous rock, locally designated Hillabee schist, which

is presumably an altered basaltic rock, like the Catoclin schist of Virginia. This supposed lead is in no sense a lode or vein, though copper has been found in considerable amounts at various localities over the area, and there are many old openings along the line of outcrop, none of which have ever proved profitable.

In 1870 copper was discovered in Cleburne and Randolph counties, on the Woods Hill property, at the Stone Hill copper-mine, 20 miles from Heflin station, on the Southern railway. Between 1874 and 1876, some 200 to 500 men were employed in extracting and hauling the black copper-ores and native copper-ores of the oxidized zone of the deposit, the total output being reported to have been 1,300,000 lbs. up to the time the work was stopped in 1879. For the first two years the black copper-ore alone was extracted; but this becoming exhausted in 1876, an attempt was made to mine and smelt the pyrrhotite-ores. In 1890, when the property was examined with a view of renewing work, the workings were under water. The 80-ft. shaft was sunk to a depth of 200 ft., and an endeavor was made to reopen the mine.

The ore-body is 24 feet thick. The richest ore is next to the walls, with 10 feet of lean ore in the center. The entire body will average 3 per cent of copper, with slight values of gold and silver. Ten feet of the ore will average 7 per cent. of copper. The unaltered rock of the walls appears to be a schistose igneous rock, presumably the Hillabee schist, though the mine is not in the main body of that formation—that is, it is not on the so-called “copper-lead.”^{*}

A report on the same property, made by R. P. Rothwell, and published in the *Engineering and Mining Journal*, Aug. 4, 11 and 18, 1877, quotes Sterry Hunt and other authorities at length upon the Ducktown and Ore Knob deposits. It says of the Alabama deposit that it is a bed of sulphide ore intercalated in a micaceous schist of Taconic age. The vein has a limonite cap, with a black-copper zone beneath which carries 30 per cent. of copper and is seldom more than 6 to 8 ft. thick, the black-copper following in a somewhat irregular manner the contour of the surface. The mine resembles the Ducktown

* See paper by Wm. M. Brewer in Proceedings of the Alabama Industrial and Scientific Society, 1897, page 13.

and Ore Knob deposits. The openings showed 400 ft. of levels with an incline shaft running 50 ft. below the levels. The bed is traceable for 1200 ft. on the surface. The schists strike N. 16° E. and dip 45° E. The ore occurs in well-defined beds 25 to 30 ft. thick, but the wall-rocks hold disseminated copper. A cross-section is given, showing a central mass of slate-ore, with 4 to 5 ft. of mundie-pyrrhotite ore on either side, lean schist-ore on the hanging-wall and good schist on the foot-wall. The description given does not accord with that of Brewer, who says that the ore will carry 30 per cent. of copper, while the mundie contains but 3 to 4 per cent. of copper. The yield of the beds, from samples assayed by Adolph Thues, is 5 to 40 per cent. Rothwell regards the deposit as a bed and not a vein. The paper presents a detailed account of the proposed metallurgical treatment, which need not be considered here.

North Carolina Examples.—In the northwest corner of the mountain-region of North Carolina there are a number of ore-deposits of the Ducktown type, of which Elk Knob, Copper Knob and Ore Knob are the best known, and the only ones on which any great amount of work has been done. The Ore Knob property was successfully worked for cuprite after the exhaustion of its secondary ores, but was forced to shut down when copper declined to less than 10 cents a pound, and, up to the present time, has not been reopened.

This deposit was described, many years ago, in two papers read before the Institute, by T. Sterry Hunt and E. E. Olcott.*

The mine is situated near New river, Ashe county, North Carolina, on a spur of the Blue Ridge between that mountain and the great Smoky range. It was worked in an irregular manner before the Civil War, abandoned during the war, and reopened in 1874. The ore occurs in a fissure-vein, cutting gneiss and mica-schist. The country dips at 45° to the south-east, while the lode is vertical and strikes N. 60° E. It is from 6 to 8, sometimes 14, ft. wide. The country-rock and the lode are altered to a considerable depth. On the surface the sulphides occur 68 ft. below the top of the hill, and on the slope at 60, 51, 48 and 40 ft.—the plane of decomposition and oxidation sloping less rapidly than the surface of the soil. The

* T. Sterry Hunt, *Trans.*, ii., 123; and E. E. Olcott, *Trans.*, iii., 391.

iron cap or gossan has been traced 1900 ft., and is underlain by carbonates and red oxide of iron, which, lower down, are replaced by sulphides. These have been traced 661 ft. on a level. The same enrichment is noticed here as at Ducktown. The ore underneath the gossan, and between it and the sulphides, is iron black, friable, drusy, crystalline, and encloses grains of quartz, garnet, magnetite and a black non-magnetic mineral. It carries 36 per cent. of copper, and has the mineralogical character, at times, of purple and vitreous ores. A quartz streak on the northwest wall holds purple ore. The black copper is from 20 to 30 ft. deep and 12 ft. wide. The unaltered sulphides had not been exhausted at the time Dr. Hunt's paper was written. E. E. Olcott says* the vein is a clearly defined fissure, striking N 61° E, and dipping 88° N.W. It shows a quartz-selvage, which is especially marked on the northwest side. The sulphide-ore is chalcopyrite, with magnetite, pyrrhotite, pyrite, quartz, garnet, epidote, hornblende, calcite, prochlorite and sphalerite. Silicates and a 4-in. streak of native copper occur in the quartz of the northwest wall, with glance and black oxide between it and the sulphide-ores. The shaft is 147 ft. deep, and, with ten other shafts, aggregates 854 ft. of shaft-sinking and 1276 ft. of levels. Some of the shafts, however, were only sunk deep enough to show that there was a good gossan present. Some 5000 tons of ore were taken out, of which 3500 tons were shipped, yielding in six months 400,000 pounds of copper, costing 8 cents a pound.

Virginia Examples.—The Ore Knob belt is continued north-eastward into Floyd and Carroll counties, Virginia, where the outcrops form what has been called "the great gossan lead" of Virginia. The locality has not been visited by the writer. The descriptions given by Hunt and others show that the deposits are exactly like those of Ducktown, have yielded large amounts of black copper-ore, but have never been worked for sulphides. The vein is commonly 20 to 40 ft., and in some places 200 ft., wide, and has been traced for 5 miles. This is a northern extension of the hornblende-schist in which the Ore Knob and Elk Knob deposits are found.

* *Trans.*, in , 391

IV. THE CATOCTIN TYPE.

General Characteristics.—Deposits of native copper and cuprite in green epidote-rocks are found at a large number of localities in the Appalachian and Piedmont plateau districts. These deposits present similar structural and mineralogical characters and are designated as the Catoctin type, since they are most common in the Catoctin schist (Catoctin mountain and vicinity). The rocks are gray or slate-colored, but when ore-bearing are yellowish-green epidotic (and in part chloritic) schists, or, less commonly, massive igneous rocks altered by ordinary hydro-metamorphism. The ore consists chiefly of cuprite and native copper, the latter often as nucleal masses surrounded by cuprite, together with small amounts of azurite and malachite, and very rarely of copper sulphide. This ore occurs in small veinlets or curving crescent- or "S"-shaped lenses of quartz, and as films on small cubic fracture-planes, and, to some extent, as grains disseminated through the rock. The ore occurs only where the rocks are fractured—sometimes irregularly checked by close and intersecting fissures; more commonly, sheeted by parallel fissures. The quartz-veinlets are rarely over a foot or two long and 4 in. wide; and their depth is usually proportional to their lateral extent. These individual quartz-veinlets, of which many occur in one zone of sheeted rock, may be regarded as what were formerly commonly designated as segregation-veins. The quartz is often clear and limpid, and includes bright metallic copper. The ore is usually seen in the outcrop; and masses of native copper are not of unusual occurrence. Commonly the surface-quartz is crackled, dull and opaque, and the copper is dull. (See Fig. 18, p. 487.)

In the half dozen or more localities visited by me, the ores of this class of deposits do not extend more than 50 to 60 ft. below the surface, usually much less. From their occurrence in shear-zones in rock which is often massive, or but slightly schistose; from the confinement of the ore mainly to the secondary quartz-veinlets; and from the character of the ore itself, it is concluded that this type of deposit is formed by a local concentration of material leached out of the altered igneous rock constituting the vein-walls, in which the copper is believed to have been present as minute particles of pyrite or chalcopyrite. The deposit is therefore a product of superficial altera-

tion, the shear-zone affording a place for the gathering of the solutions and the deposition of material. These "veins" seldom outcrop as actually continuous masses, but can be traced for miles by the copper-bearing débris. Notwithstanding the large amount of float-rock and the extent to which it can be traced, the deposits are believed to be valuable for the copper contained for less than 50 feet in depth.

So far as known, but small shipments of ore have ever been made from such deposits, but rich specimens have been found, and pits 10 to 50 feet deep have been sunk at several localities. The most promising are those at the base of the mountains, 18 miles west of Barboursville, in Greene county, Va., and those east of Front Royal, on a spur of the most prominent mountain of this part of the Blue Ridge, known as High Knob. The nearest settlement to the last place is Linden.

The Linden District.—Linden, Va., is 76 miles from Washington, on the Manassas branch of the Southern railway. A large tract of land near here has recently been bonded by a number of capitalists of Pittsburgh, Pennsylvania, after an examination of the large amount of copper-float on the property. This land was originally granted to Lord Fairfax, and subsequently transferred to Chief Justice Marshall, from whom it has come to the present owners. In the early part of the century the occurrence of copper at this place was well known, and shallow pits were sunk at several places; but no shipments were made until 1861, when 35 tons were collected from the surface and from a 50-ft. shaft which was sunk at that time. This ore was shipped abroad, and averaged over 10 per cent in copper.

In January, 1900, I visited the workings, which are upon a spur of High Knob, 1750 ft. above sea-level. The ground is in part an open and cultivated tract formed by a flat top of the spur. To the west the surface is more rugged, is densely wooded, and descends abruptly to the headwater valley of the Rappahannock. To the east the descent is less abrupt in a succession of benches, densely covered with timber for about a mile.

According to Mr. Arthur Keith, who has made a general study of the Appalachian region, the Blue Ridge, of which High Knob is a part, is formed of igneous rocks which probably occur as two flows—the upper basaltic; the lower dioritic.

These rocks have been generally much altered by dynamic metamorphism and secular decay, and now form greenish chloritic and epidotic schist, which he designates the Catoctin schist. This schist is penetrated by a younger and clearly intrusive granite. The two rocks often occur intricately intermingled, so that outside of the main belts of each there are areas where the relations of each can only be shown on a very large scale map. The most peculiar feature of the granite to the ordinary observer is its complete physical alteration near the contact. It is altered to a fine schist or finely laminated shale, or may even resemble a leafy black slate, in which no trace of its original character can be recognized by the eye. This is the material seen along the road to the copper-mine south of Linden, near the school-house. According to Keith, both granite and Catoctin schist are Algonkian. The occurrence of copper-ores in the Catoctin schist is noted by Keith, who says.*

"Deposits of copper in the schists have long excited interest and led to mining operations. The amount of ore, however, appears not to have justified any considerable work. Such deposits have been worked on the Blue Ridge east of Front Royal and along the northern end of South Mountain."

The copper ores of South Mountain are in this Catoctin schist.†

Except in the shear-zones, where copper is found, the Linden rock is not schistose, and commonly shows well-defined basaltic characters. It is undoubtedly a part of the younger or upper epidote-schist of the Catoctin, as described by Keith.

This rock, which is familiarly known as greenstone, is an altered basalt, in which, by the processes of ordinary hydro-metamorphism, epidote has been so abundantly developed from the original augite and mica as to give the rock its characteristic color, namely, a bluish-green when the rock is fresh from the shafts, but commonly a yellowish-green on weathered faces. It contains so much epidote that it is very enduring: knobs and bunches of epidote frequently protrude above the corroded surface. The rock is not schistose except in the shear-zones. Here the fractures are marked by silky chlorite,

* "Geol. of Catoctin Belt," 14th Ann. Rept. U. S. G. S., part ii., p. 309.

† See *Trans.*, xii, 82.

often in bunches. The copper occurs chiefly as the native metal, filling fractures, or in minute quartz-films or veins.

In traveling from Linden by railroad to the property (a distance of about three miles in a direct line), one encounters near the mill a little to the south of the town, a mass of altered granite, forming the "shale," adjoining the basic rock and apparently intruded in it. This is the supposed eastern extension of the copper-"vein," and shows a highly altered basic eruptive carrying seams and strings of quartz. At a distance of about one-half mile from Linden the granite "shale" is left behind, and the ground is strewn with a very dark-gray basic rock, somewhat resembling diabase. This rock extends to the mines and for some miles on either side, forming, I am told, the summit of High Knob itself. In general, it does not form prominent outcrops, but shows as abundant angular boulder-masses scattered over the fields. The fragments are from one to two feet in diameter, sometimes slightly larger. Where rock outcrops do occur there is no pronounced jointing, and the rock is quite massive without any appreciable schistosity. These characters prevail over the entire area except in the immediate vicinity of the places from which the copper is obtained.

The present workings consist of a shaft about 35 ft deep and of an open cut 30 or 40 ft. long and 10 or 15 ft. deep at its extremity. The old workings comprise a shaft that is 42 ft. deep, but now filled with water, and several shallow pits. These are situated about a mile west of the present Sealock House. In the vicinity of these workings the rock is jointed, and on the western side shows well-marked schistosity. No defined vein was seen—the ore occurred in quartz strings in the altered rock. Before taking up the property the engineer in charge spent some weeks looking over the ground, and traced the copper float up the hillside to a line running approximately southeast and northwest. It was supposed that this line marked a lode extending for six or seven miles in a general northwest and southeast direction. Furthermore, the float on the summit of the ridge indicated three parallel veins. An examination as careful as the brief time at my command would permit convinced me that the supposed veins do not exist; that the copper occurs along lines of jointing or of schistose move-

ment; and that the rich copper-ore found is a product of concentration by surface-waters from disseminated particles of chalcopyrite present in the original rock. The ore is necessarily more abundant in the upper zone, because there the movement which produced the joints and the schistosity formed open spaces, which have been filled with quartz and ore. I am inclined to believe, therefore, that the origin of the ore is due solely to the concentration of the copper from metallic sulphides, which may have been original constituents of the rock. In the shaft the rock is closely sheeted, the planes being from 6 in. to 1.5 ft apart, and the fractures running in a southeasterly direction. There is another system of fractures, more widely spaced, and later than the former, which they cross at an angle of about 60° , running in a southwesterly direction. One of these forms the east wall of the shaft, and it was along this that the greater part of the ore taken out was found. There is another less defined system of fractures, dipping about 20° to the south, whereas the former fractures are nearly vertical, the dip being between 80° and 90° to the west. At a depth of 30 ft. the shaft encountered a clay seam lying on one of the flat fractures, and clearly connected with a vertical fracture, down which waters had percolated. This clay seam feathers out on the north to a few inches, and increases in width on the south to 2 or 3 ft. It is underlain by very solid blue rock, and may possibly mark a fault along which the ore-body has slipped to the south. No ore whatever has been found beneath this clay seam, and none immediately above it.

The old shaft, a mile and a half further west, showed on its dump much of the blue igneous rock. The shaft was driven at an inclination of about 70° to the south, and is said to have yielded some good ore. The outcrops in the immediate vicinity are on very rugged ledges further down the mountain-side, and clearly do not belong to the same supposed lode as that on which the shaft is located. The ore is quite irregularly bunched and seems to occur more especially where the vertical fractures are bent over to the north, showing a minute puckering or over-folding of the schist. A few blasts have been made on these outcrops, but no well-defined vein was seen. The ore so far taken out consists chiefly of native copper and cuprite, with

small amounts of malachite and, very rarely, azurite. It is always associated with quartz, and the gangue is a bright green rock which is clearly an alteration of the general country-rock. In the material taken from the shaft some of this green rock showed minute specks of a metallic sulphide which appears to be chalcopyrite, and other specks of cuprite scattered through the rock. In this case the copper was not connected with any quartz, and it is believed that this material represents the original character of the copper-bearing rock which has been leached in the upper part of the workings, permitting the concentration of the copper.

General Distribution of the Catoctin Type.—Similar native copper and cuprite ore is found very commonly with epidote schist, not only in the mountain region, but over the Piedmont plateau. It is evident that the association of epidote (and, to a lesser degree, of chlorite) and the native copper is a constant one, for which reason it is believed that the processes incident to the formation of the one led to the formation of the other. Such ores occur near Virgilina, Virginia, near Charlotte, North Carolina, and in many scattered localities through the South.

The Sims property on the eastern slope of the Blue Ridge, 5 miles north of Stanardsville, in Greene county, Virginia, shows the same geological conditions observed at Linden. Native copper and cuprite occur in bunches along shear-zones in diabase (Catoctin schist). The rock, like that of Linden, is often schistose, is penetrated by tongues of granite, and is shaly near the contact. Local segregations and many small lenticular masses of quartz occur along the shear-zone, usually trending across the direction of shearing. The shear-zone has a course of S 80° W. magnetic, and dips 70° to 80° S. A number of shallow openings have been made along these zones, and on the Sims property a shaft 30 feet deep has been sunk. No well-defined ore-body has as yet been seen, though good ore has been found at the surface-diggings both at this place and at a locality 2 miles further west. The amount of development-work does not as yet warrant a positive opinion as to the future of these deposits; but inasmuch as the ore is the result of alteration, and the original source is as yet unknown, there is some doubt as to their future. At the western pit, the shear rock shows pyrite and chalcopyrite in small amounts

disseminated through the altered rock. These minerals occur only where quartz and epidote are found, and the small quartz lenticules are often found surrounded by a zone of epidote carrying pyrite. The material from the western opening shows movement, and is in part brecciated. A short cross-cut, driven 25 ft. north at a depth of 30 ft., cuts through the curly schists of the shear-zone, but shows no ore. The locality is perhaps less favorable for exploration than that of the Linden property, and it cannot be regarded as an encouraging place for future development.

Distribution of the World's Production of Pig-Iron.

BY JOHN BIRKINBINE, PHILADELPHIA, PA.

(Washington Meeting, February, 1900)

SECRETARY'S NOTE—In printing this paper in the present volume, the figures given in the pamphlet edition have been brought more nearly up to date, the product of 1899 being in many instances inserted.

IRON-ORE RESOURCES.

In a paper presented to the Institute in 1897,* I discussed the iron-resources of the United States as then developed, calling attention to some principal sources upon which other countries depended.

The following statement will give a general idea of the amounts, as compiled from the latest official records, of ores won, and metal produced, in the nations which are important contributors to the world's output. Unfortunately these are not all contemporaneous, since in some countries the statistics do not appear until after one or more years. The statement covers not only pig-iron and iron-ore, but also manganese-ore—the manganese mined being principally used in the production of spiegeleisen or ferro-manganese, and these alloys being generally included in the pig-iron output.

Table I, which epitomizes the present situation, shows respectively the countries and the quantities of iron-ore and man-

* "The Iron-Ore Supply," *Trans.*, xxvii., 519.

TABLE I.—*World's Product of Iron- and Manganese-Ore and Pig-Iron.*

1 Country	Year	2 Iron-Ore Tons	Year	3 Manganese- Ore Tons	Year	4 Pig-Iron Tons
United States	1899	24,683,173	1899	9,935	1899	13,620,703
Great Britain	1898	14,176,938	1899	231	1899	9,305,319
Germany and Lux- emburg . . .	1899	17,989,665	1898	43,354	1899	8,029,305
France . . .	1899	5,067,500	1898	31,900	1898	2,567,388
Russia . . .	1897	4,107,467	1899	376,445	1899	2,222,469
Austria Hungary	1897	3,035,005	1897	5,904	1897	1,308,423
Belgium . . .	1898	217,370			1899	1,036,185
Sweden . . .	1899	2,435,200	1899	2,622	1899	497,727
Spain . . .	1899	9,234,302	1899	138,419	1899	296,840
Canada . . .	1899	68,891	1899	1,412 ?	1899	94,077
Italy . . .	1897	200,709	1897	1,608	1897	8,333
Greece . . .	1898	485,159	1899	15,300		..
Algeria . . .	1898	473,569				..
Cuba . . .	1899	368,758	1899	13,636		..
Newfoundland	1897	58,940				..
Turkey . . .			1899	38,305		..
Brazil . . .			1899	62,178 ?		..
India . . .			1899	77,348 ?		..
Chili . . .			1899	36,996 ?		..
Japan . . .			1899	6,370 ?		..
Portugal . .			1899	4,130 ?		..
Java . . .			1899	910 ?		..

gancsc-ore mined, and of pig-iron produced in the year specified in the column preceding each statement of quantity

The quantities are given in metric tons (2204 lbs.) except for the United States, Great Britain and its dependencies, and Cuba, where the avoirdupois long ton of 2240 lbs. is in use.

No estimate has been attempted for countries which, though producing some ore or metal, publish no statistics; reported exportations of manganese-ores from such countries are, however, noted.

This table shows that, in the production of iron-ore, the United States is considerably in advance of the German empire, its next competitor, and that Great Britain, Spain, France, Russia, Austria-Hungary, Sweden, etc., follow in the order named, while in the output of manganese-ores, Russia leads, with Spain second, the German empire third, etc., the product of the United States being relatively unimportant.

In the production of pig-iron the United States is shown to be well in the lead, followed by Great Britain, Germany, France, Russia, Austria-Hungary, Belgium, Sweden, etc.

The following summarizes the conditions in various countries.

Great Britain.—This country, which stands next to the United States in the production of pig-iron, held the foremost position in this industry for almost a century, until the year 1890. Before the introduction of the Bessemer process, practically all the iron-ores smelted in British blast-furnaces were produced from native mines. At the present time, most of the domestic ores used are carbonates,—Cleveland, the principal mining district, furnishing nearly one-half of the entire supply of native ores (in 1899 about 5,600,000 long tons). In the development of the Bessemer steel industry, it became necessary to supplement the British ores by liberal additions of foreign ores, which were principally obtained from Spain, Greece, Algeria, Elba, France, etc.

The maximum domestic product of iron-ore was reached in 1882, when 18,031,957 gross tons were won.

In the year 1899, about one-third of the total British consumption of iron-ore was imported, but these importations, by reason of the high percentage of iron contained in the ores, furnished more than one-third of the pig-iron manufactured. The importation of iron-ore has gradually increased, the largest being in the year 1899, viz.: 7,055,176 gross tons, of which Spain contributed 6,186,022 tons.

The production of pig-iron in Great Britain has not advanced lately in the same proportion as that of her principal competitors, the United States and Germany. The maximum output was 9,305,319 gross tons in 1899.

A considerable proportion of the pig-iron and the iron and steel manufactures of Great Britain is exported, amounting in 1898 to 3,247,368 tons, of which 1,024,296 tons was pig-iron, the rest being manufactures of iron and steel.

German Empire.—Iron-ores are liberally distributed throughout the German empire; but the greatest development is in the Grand Duchy of Luxemburg and German Lorraine, where oolitic ores, locally known as *minette*, are found in strata, variously classified as the uppermost Lias, or lowest members of the "brown Jura" series, in a length of rather less than 40 miles in Germany, and a width of about 8 miles. More than one-half of the output of the German empire comes from this *minette* district of Lothringen and Luxemburg. The average analyses of the ores show that they carry from 28 to occasion-

ally 48 per cent of iron, with phosphorus ranging from 0.5 to 2 per cent

The ore-district of Siegerland, belonging wholly to the Lower Devonian, ranks next in importance. Most of the ores are spathic, although in some cases red hematites occur. The district contributes about one-tenth of the total for the empire. In Hessen-Nassau red hematites are associated in some instances with brown ores, and manganiferous iron-ores occur in the upper Devonian rocks, forming an important supply for the Westphalia blast-furnaces. The annual output constitutes about 7 per cent. of the total domestic supply of Germany.

Probably five-sixths of the German product consists of brown hematite-ores in various forms. Practically the whole output of the German mines is consumed in the blast-furnaces of the empire, and, in addition, a considerable amount of foreign ore is imported, chiefly from Sweden. Germany exports *minette* ores, chiefly to France and Belgium. The maximum German product of iron-ore, 17,989,665 metric tons, was reached in 1899, in which year 8,029,305 tons of pig-iron were manufactured. In 1898 manganese-ore was mined to the amount of 43,354 metric tons—the greater portion in Prussia.

France—The iron-ore deposits of France, though numerous, are scattered, and, except in the case of the oolitic formation in the eastern portion of the country, there are no deposits capable of feeding any considerable number of blast-furnaces

The maximum product of iron-ore reported for France was 5,067,500 metric tons, in 1899. The largest pig-iron production was in 1899, 2,567,388 metric tons.

Since the loss of Alsace-Lorraine, as a result of the Franco-German war, a considerable amount of iron-ore has been imported into France from the region which was annexed to Germany. In 1897, the importation from Germany, Algeria, Spain and Italy amounted to 2,137,860 metric tons. Iron-ore is also exported, though, from the maximum (3,552,845 tons) in 1873, the amount has gradually declined, until in 1898 but 236,169 tons were shipped. The product of manganese-ore in 1898 was 31,900 metric tons.

Russia.—The iron-industry of Russia dates approximately from the year 1700, and, until a recent period, all the pig-iron produced was manufactured with charcoal, chiefly in the Ural district.

The Russian mines are divided into districts, each under the supervision of a special mining inspector. There are four such Government districts in the Urals, one in Northern Russia, and one in Poland.

The private mines are under the inspection of district engineers, of whom there are eight in the Urals, four in the Caucasus, six in western and six in eastern Siberia. In the central and southern portions of the Ural district there are extensive deposits of brown hematite.

The iron-works of eastern Russia—*i.e.*, of the Governments of Perm, Viatka, Ufa and Orenburg, belonging to the mining regions of the Ural—smelt magnetic and brown ores chiefly; but red hematite and siderite are also found. Some remarkable deposits of magnetic iron-ore occur at Mt. Blagodät and Visokaia in the central Urals, and at Mt. Magnitwaia in the southern Urals. The deposit of Mt. Visokaia yields ore containing from 63 to 69 per cent. of iron, which, it is claimed, is often smelted without the use of flux.

The manufacture of pig-iron received a decided impetus when works were successfully built to manufacture this metal with mineral fuel in the south of Russia, where rich iron-ore deposits exist; and it is expected that the rapid advance of this district will soon enable it to outrank the Ural region as a producer. The deposits are chiefly magnetic, specular and red hematite ores, containing from 60 to 68 per cent. of iron.

Olonetz and Finland have lake- and bog-ores, low in iron and relatively high in phosphorus. In southern Poland brown hematite ores containing 40 per cent. of iron are found in rocks of Devonian age.

New iron- and steel-works are now building in Russia; and it is probable that this industry will show a further advance. The maximum iron-ore production recorded was 4,107,647 metric tons in 1897; but this was probably surpassed by the product of 1898, and also by that of 1899. The record of 2,222,419 tons in 1898 showed the maximum pig-iron product up to that date; but it is probable that this also was surpassed in 1899.

Practically all the iron-ore mined in Russia is smelted in the blast-furnaces of that country; and the pig-iron manufactured is consumed in the various iron- and steel-industries which the

Government encourages. Small amounts only have been exported.

Russia possesses the best-known developed manganese-mines, which contribute more than one-third of the world's consumption. These ores, mined almost wholly in the Caucasus, are exported to the United States and to various European countries.

No other deposit of manganese-ore now worked approaches that of Chiaturi in the capacity to produce large quantities of high grade ore at low cost. The ore, as exported, carries 46 to 56 (the average being probably 51 to 52) per cent. of manganese, with not more than 8 per cent of silica. Most of it is exported from the ports of Poti and Batoum on the Black Sea. Of the 210,106 tons exported in 1897, Germany received 70,810; Great Britain, 68,650; and the United States, 42,200 tons, while 28,446 tons were used in Russia.

Austria-Hungary—The most important deposits of iron-ore in Austria are the spathic iron-ores of Styria. From the large deposit of Erzberg, near Eisenerz, the "Noric iron" of Tacitus and other authors is reported to have been prepared; and the industry has continued from the date of the Roman occupation to the present day. Spathic ores occur also in Carinthia and in the north of Hungary.

The greatest product of pig-iron was 1,808,423 metric tons, in 1897. The greatest amount of iron-ore won, 3,035,005 metric tons, was also reported in the same year. Of this amount, slightly more than one-half was obtained in Austria, and the remainder in Hungary.

The exports of iron-ore from Austria amount to about 100,000 tons per annum; and a smaller amount (about 75,000 tons) is annually imported. About 12,000 tons of manganese-ore are annually mined in Austria and Bosnia.

Belgium.—Belgium produces a considerable amount of pig-iron and steel, much of which is exported, but the greater portion of the iron-ores used are imported. Roughly speaking, about one-ninth of the iron-ore smelted in Belgian blast-furnaces comes from native mines, consisting of oölitic iron-ore (red hematite), somewhat similar to the Alabama fossil-ores, and occurring in the older Silurian or Devonian formations, minette-ore (oölitic limonite) worked in the extreme south of

the Province of Luxemburg, and extending also into France, Luxemburg and Germany; bog-ore from Campine; and man-ganiferous iron-ore from the province of Liege. The chief domestic supply comes from the Luxemburg and Lorraine oölitic limonite-ores, carrying 30 to 35 per cent. of iron. The foreign imports are chiefly from Germany, France, Spain, Algeria, etc., the ores from Spain and Algeria being used in the manufacture of Bessemer pig. Roughly speaking, more than one-half of the Belgian pig-iron is forge-iron, one-third is of Bessemer, and one-tenth is of foundry-grades. Considerable mill-cinder also is used in the furnace-charges.

In round numbers, about 2,500,000 metric tons of iron-ore are annually imported, and 300,000 tons are exported.

The greatest product of iron-ore was 1,019,231 metric tons in 1865; and the total gradually decreased, with slight fluctuations, until in 1898 but 217,370 metric tons were won. The product of pig-iron, however, advanced until 1,036,185 metric tons were manufactured in 1899.

Sweden.—The high quality of Swedish iron and steel has been famous for centuries. The industry is almost entirely dependent on magnetic ores, although some hematite or specular ores, usually called "mountain-ores" are also used, and a small amount of "lake-" or bog-ore is mined in several provinces. The Swedish iron-ores vary in iron from 30 to 70 per cent., averaging about 50 per cent., and generally (except in the north) contain very little phosphorus.

Prof. Åkerman says that, of the iron-ore mined in Sweden, from two-thirds to three-quarters is magnetite; from one-third to one-quarter specular; and the remainder (about 1000 tons) lake- or bog-ore. The principal iron-ore deposits extend across the country from the Dannemora region, north of Stockholm, to their termination at some distance from the Norwegian boundary, and cover a length of about 180 miles. Most of the ores are found in the Archean rocks. Southward, the ore-region continues to the middle part of the province of Ostergotland, and northward to the northern boundary of the province of Dalecarlia, thus covering 5800 square miles.

In the vicinity of the Arctic circle are found the large beds of Gellivara, Kirunavara and Luossavara, located in Swedish Lapland, and connected by a railroad, 129 miles long, with the

harbor of Lulea, at the north end of the Baltic sea. The quality of these ores is variable. They are usually rich in iron; but, although good Bessemer ores occur among them in considerable quantity, the greater part are high in phosphorus. The percentage of sulphur, however, is small. Most of the rich magnetic ores here mined are exported, chiefly to Germany, Austria and England, being transported about 1700 miles to reach some of the German and English furnaces.

The annual increase of this export-trade has shown the necessity of a harbor open all the year (that of Lulea being closed for six months by ice); and a railroad is now being constructed to Victoriahaven, in Norway.

While the pig-iron and steel manufactured in Sweden have enjoyed a high reputation on account of their purity, the industry has been entirely dependent on charcoal as a fuel, and therefore has not shown the great quantitative advance exhibited by some of the other iron-producing countries. The pig-iron product reached its maximum (538,197 metric tons) in 1897, and fell to 497,727 tons in 1898. On the other hand, the advance in the production of iron-ore, especially since 1892, when the Gellivara deposits were first exploited, has been rapid. The year 1899 shows the maximum of 2,435,200 metric tons, of which about 1,525,000 were exported.

Sweden exports considerable quantities of iron and steel, chiefly in the form of rods, sheet-iron, and other manufactured articles.

From 2000 to 3000 tons of manganese-ore are annually mined, most of which is consumed by the home industry.

Spain.—By reason of the lack of good mineral fuel, the Spanish manufacture of pig-iron has not attained much importance, although Nature has distributed throughout the country large deposits of rich and pure ores. The iron-ore bodies of the Biscayan provinces, in the north, have been the principal contributors, but there are also series of valuable deposits of iron-ore extending along the southeastern coast of Spain, commencing with those at Porman, continuing at moderate distances from the coast through the provinces of Murcia, Almeria, and Malaga, and finally trending northwest to the district of Sevilla, further inland.

The ores of Biscaya are, near the surface, hydrated per-

oxides, occupying veins in rocks of Cretaceous age, and quite rich and fairly free from phosphorus and sulphur. As greater depths are reached, the mass of the unchanged deposit below the gossan or oxidized outcrop is found to be spathic iron-ore, containing a larger proportion of sulphur than the zone above.

The mines most extensively worked are in the vicinity of Bilbao, and form three groups, known as the Somorrostro, Galdames and Ollargon.

In the province of Murcia, the Porman deposits are well known, having exported considerable amounts of ore. In addition, both red hematite and magnetite occur in the interior of the province. Red hematite is obtained from the Morata mines, and also from Santa Isabel.

In the province of Malaga are the well known magnetite mines of Marbella, from which considerable quantities of iron-ore are exported.

Huelva has several deposits of iron-ore, but, up to the present time, has exported iron pyrites only.

The total Spanish product of iron-ore in 1899 was 9,234,302 metric tons, that being the maximum year reported. Of this amount 8,613,137 metric tons were exported, while the greater portion of the remainder was used in the manufacture of 295,840 metric tons of pig-iron—the largest annual product of iron thus far reported in Spain.

About 130,000 tons of manganese-ore per year are exported from the province of Huelva. The report for 1899 is 138,419 metric tons, all of which was carbonate. In addition, about 300 tons of oxide of manganese, carrying about 50 per cent., was obtained from the provinces of Oviedo and Teruel.

From the south of Spain about 400,000 tons of manganimiferous iron-ores is annually exported; but these are all classed as iron-ores.

Other Countries.—None of the remaining countries have as yet attained prominence in the production of either pig-iron or iron-ore.

Canada has numerous deposits of iron-ore, and is developing an important iron-industry. Extensive mining operations on the north shore of Lake Superior will be begun in 1900. In Nova Scotia, red and brown hematites are won; in Ontario, red hematite and magnetites occur. In British Columbia there

are also important deposits of magnetite. The largest reported production of Canadian iron-ore was in 1893, when 125,602 short tons were produced. In 1899, 94,077 gross tons of pig-iron were manufactured.

Newfoundland has an extensive body of red hematite ore, carrying about 50 per cent. of iron, which is won by quarrying, and exported to supply blast-furnaces in Nova Scotia; a few cargoes going to Europe and the United States. In 1897, it is reported that 58,940 tons were mined. A large plant is being constructed to utilize this ore.

Algeria has important deposits, principally of magnetite, red and brown hematite and siderite. The mines at present worked are in the Department of Constantine, and produce annually from 350,000 to 650,000 tons of iron-ores, all of which is exported. The amount shipped in 1897 was 441,467 metric tons, consigned to England, France, the United States and Belgium.

Cuba possesses rich bodies of iron-ore in the extreme south-eastern portion of the island, in the province of Santiago. They are of the red hematite variety, and are operated by American companies. The maximum production was reached in 1897, when 457,561 gross tons were mined. In 1899, the product was 368,758 gross tons. A manganese-mine in the same province produced 13,636 tons in 1899.

Greece abounds in iron-ores, principally carbonates, hematites and magnetites, most of which contain manganese. The maximum product was 485,159 metric tons in 1898.

The manufacture of iron in Italy is subject to a disadvantage in the scarcity of good fuel; but a considerable amount of iron-ore (red hematite and specular, with some magnetite) is mined and exported, mostly from the Island of Elba. It usually carries from 60 to 62.5 per cent. of iron, with 0.009 to 0.004 per cent. of phosphorus. In Lombardy and Piedmont iron-ores are also mined, while a small amount of charcoal pig-iron is made in the provinces of Lombardy and Tuscany from native ores. The production of iron-ore in 1897 was 200,709 metric tons. In the same year, 8333 metric tons of pig-iron were produced, and 1608 tons of manganese-ore were mined.

Asia, Africa and South America have iron-ore deposits, but only India, China, Brazil and Mexico can be considered as

manufacturing iron in appreciable amounts. Manganese-ores of good quality are mined in quantity in Chili, Brazil, Japan, the Republic of Colombia, India and Turkey, and are exported.

United States—In 1899 the United States, the foremost pig-iron producing country of the world, surpassed its former highest record, turning out 13,620,703 gross tons of pig-iron. To supply the raw material for this amount of iron, the iron-ore mines were actively wrought, and 24,683,173 gross tons were mined.

Until 1893 the United States was practically a producer for the home market only; but in that year the exports of iron and steel exceeded in value the imports, and the difference has become annually more marked, until in 1899 the value of the iron and steel exports was \$105,689,645, and that of the imports only \$15,799,206. Most of the exports were manufactured products, thus securing a larger remuneration to producers than if they had been raw materials.

The iron and steel exports of 1899 included steel rails, valued at \$6,122,382, wire, \$5,526,930; pig-iron, \$3,282,241; plates and sheets, \$2,047,301, wire nails and tacks, \$1,955,773; castings, \$1,348,133; and cut nails, \$482,382.

This position has been attained by the liberal use of mechanical and labor-saving devices, whereby the cost of handling the raw materials entering into the production of pig-iron, and of the metal itself, has been reduced to a minimum.

In the winning of iron-ore and coal, electric- and compressed-air drills, improved explosives, carefully designed timbering, and scientific methods of mining, hauling and raising the mineral won, have reduced the cost of these materials, placed on cars for transportation. At the coke-ovens, appliances decreasing the amount of labor employed, or obtaining better yield of coke, and at some plants the collection of the by-products, have cheapened the manufacture of the necessary fuel. Transportation-companies have expended vast sums in the building of shipping- and receiving-docks and of large economical vessels and barges to transport the iron-ores from the Lake Superior region to the Lake ports. The railroad-companies have co-operated with large cars, powerful locomotives, substantial road-beds, etc., to enable the blast-furnaces to transport rich ores for distances as great as 1500 miles, at so low a cost that they have displaced leaner local ores.

While the wages paid to American labor are, as a rule, higher than those which obtain elsewhere, yet the liberal use of labor-saving machinery has increased the output per man, so that the labor-cost per unit of product is often less in the iron- and steel-industry of the United States than elsewhere.

The State of Pennsylvania stands pre-eminent as a producer of iron and steel, contributing, in 1899, 6,558,878 gross tons of pig-iron, a greater amount than has been credited in any one year to any foreign country, with the exception of Great Britain and the German empire. The statement has been made that in the district surrounding Pittsburgh the profits of the iron- and steel-industry, at the present time, are greater than those realized in any gold-district of the world.

Although the State has numerous deposits of iron-ore, the bulk of the ore smelted came from the Lake Superior region, being transported from 1000 to 1500 miles, from the mines to the blast-furnaces.

Ohio, with a total of 2,378,212 gross tons of pig-iron in 1899, is second, contributing about one-sixth of the total for the United States. Practically all of the iron-ore used came from the Lake Superior region, although a small amount of native carbonates was utilized.

Illinois owes its prominence as an iron-ore producer to a good home market, and to the fact that ores from the Lake Superior region, and coke from Pennsylvania and West Virginia, can be readily assembled there. These facts made it possible for a State mining no iron-ore to contribute in 1899 a total of 1,442,012 gross tons of pig-iron, or slightly over one ninth of the production of the United States.

In the northern central part of Alabama, Birmingham nestles in a great fold in the Clinton Fossil formation, in close proximity to immense iron-ore beds and coal-fields. In addition, brown hematites from northern and eastern Alabama and similar ores from Georgia and Tennessee are used. Alabama contributed 1,083,905 gross tons of iron-ore in 1899, or about 8 per cent. of the total for the United States. Seventeen other states manufactured pig-iron in 1899; but no one of them reached 400,000 tons. The amount of iron-ore mined in the United States has shown a considerable increase in late years. In 1880, the total was 7,120,362; in 1889, it was 14,518,041,

and in 1898, it was 19,433,716 gross tons; while in 1899 it reached 24,683,173 tons.

The iron-ores of the United States are commercially divided into four classes, viz red hematite, brown hematite, magnetite and carbonate. The major portion of the ore mined is red hematite, the brown hematite, magnetite and carbonate following in order, as shown by the accompanying statement of the figures for 1899 :

TABLE II — *Product of Iron-Ore in the United States in 1899.*

Variety	Production, Gross Tons	Percentage
Red Hematite,	20,004,399	81 04
Brown Hematite,	2,869,785	11.63
Magnetite,	1,727,430	7 00
Carbonate,	81,559	0 33
Total,	24,683,173	100 00

Some iron-ores are imported from foreign countries, principally from Spain, Cuba and Greece; and cinder from puddling furnaces and "blue billy" (the residuum from burning pyrites in the production of sulphuric acid) are used in producing pig-iron. Cinder containing iron and manganese, resulting from the treatment of zinc ores, is also employed in the manufacture of spiegeleisen.

The Lake Superior region, which has a world-wide reputation on account of its excellent iron-ores, which are cheaply won and transported long distances, consists of five ranges, mentioned below in the order of their development.

The Marquette range in Michigan, on the southern shore of Lake Superior, made its first shipment in 1854. Its ores are usually of high grade and hard, and many are of Bessemer quality, although some non-Bessemer ores are also largely mined. Cargo shipments show a range of from 38.85 to 68.65 per cent. of iron in the natural state, with moisture from 0.45 to 15.29 per cent. The leaner ores have special value, either because of low phosphorus contents, or as being highly siliceous and cheaply mined, making them desirable for mixtures with low-silica ores. The total reported shipments to the close of 1899 amounted to over 56,000,000 tons, of which over 3,750,000 tons was forwarded in 1899.

The Menominee range lies almost wholly in the northern peninsula of Michigan, only two active mines being in Wis-

consin It was first exploited in 1877. The ores are of high grade, but not so hard as those of the Marquette range. Both the Bessemer and non-Bessemer ores find a ready sale. The iron in the natural state ranges from 60.9 to 39.46 per cent., with from 2.18 to 11.20 of moisture. The total output of the range to the close of 1899 is about 30,750,000 tons, of which 3,300,000 tons were shipped in 1899.

In the Gogebic range, also on the southern shore of Lake Superior, but further west than the Menominee and Marquette ranges, most of the important mines are in the State of Michigan, but like the Menominee range it extends across the State border into Wisconsin. The first shipment was made in 1884. The iron-ores are both Bessemer and non-Bessemer in character, carrying from 60.09 to 47.33 per cent. of iron in the natural state, and 8.14 to 14.91 per cent. of moisture. Up to and including 1899, the total shipments have been over 28,250,000 tons, of which amount 2,750,000 tons are credited to the year 1899.

The Vermilion range lies back from the northwestern shore of Lake Superior, about eighty miles north-northwest of Duluth. The first shipments of ore were made in 1884. The ores are usually hard, although some are comminuted. They are rich in iron, carrying from 65.39 to 56.19 per cent. in the natural state, with 1.45 to 7.96 per cent. of moisture. They are both Bessemer and non-Bessemer in quality. The total shipments to date are over 13,500,000 tons, of which 1,750,000 tons were shipped in 1899.

The Mesabi range, also in Minnesota, lying to the south and west of the Vermilion range, is the youngest of the ranges in development, no ore having been shipped from it before 1892; but its large deposits of rich, easily mined ore have rapidly brought it to the front, and it contributed some 6,625,000 tons in 1899, or over 40 per cent. of the total for the Lake region. Since its opening it has shipped a total of over 23,500,000 tons. The ores carry from 59.06 to 50.20 per cent. of iron in the natural state, and from 6.81 to 14.7 per cent. of moisture, being both Bessemer and non-Bessemer in character. They are soft and generally finely comminuted, which limits their use somewhat in the blast-furnace.

Since the opening of the Lake Superior iron-ore region, in

1854, a total approximating 152,000,000 gross tons of iron-ore has been mined, of which more than half has been won in the past seven years (1893 to 1900).

While the Lake Superior region probably contributed three-quarters of the iron-ore supply of the United States in 1899, there are other districts which supply large amounts. Alabama, Tennessee, Virginia and Georgia annually furnish large quantities of red and brown hematites. New York, New Jersey and Pennsylvania have large deposits of magnetites. The Cornwall ore-hills of Pennsylvania, and the Lake Champlain region of New York, have been for more than a century noted sources of supply. Colorado, Wyoming, Utah, New Mexico and other points in the west also have important deposits of iron-ore; as have Missouri, Texas, Kentucky, etc.

Colorado is advancing in iron-and steel-production from ores mined in that State, supplemented by others drawn from eastern Wyoming and southern New Mexico. The ores used are of Bessemer grade, unusually low in phosphorus.

While the United States is one of the largest consumers of manganese in the world, the deposits at present worked in this country are very uncertain as to both the quantity obtainable, and the composition of the ore. In the year 1899, nine States contributed a total of 9,935 gross tons. The importation, as would naturally be expected, is large, practically all of the manganese-producing countries, headed by Russia, contributing to the 188,349 tons imported in 1899.

Hydraulic Pumping-Plant on the Snake River, Idaho, for Power, Irrigation and the Treatment of Gold-Sands.

BY JOHN BIRKINBINE, PHILADELPHIA, PA.

(Washington Meeting, February, 1900)

THE following data, collected during a visit to the Snake river district, in Idaho, are offered as indicating the possible utilization of a water-fall for irrigation by pumping, the working of gold-placers, the generation of electricity for light and power, and possibly for manufacturing purposes. For irriga-

tion and placer-washing, a portion of the water is applied to wheels and pumps to elevate another portion.

These notes do not describe any new methods in hydraulics, in electrical development, in irrigation or in hydraulicking auriferous sands, but rather suggest the possibility of various applications of the water-power available, either contemporaneously or in different seasons.

As the minimum flow in the Snake river is in the winter, when the snows on the mountains are not melting, while the normal or possible flood-flow is during the season when irrigation is necessary, the application of water for other purposes may not interfere with irrigation.

The Snake river heads on the continental divide, close to the Yellowstone Park in the State of Wyoming, and flows south-westward through eastern Idaho, then westward, and then northward, forming a portion of the boundary between Idaho, Oregon and Washington, and finally uniting with the Columbia river in the latter State. The three prominent falls on the stream, after it has obtained considerable volume, are the Idaho, the American and the Shoshone falls, the latter being the most noted.

The data here given concern the conditions at the American falls, the point where the Oregon Short Line railroad crosses the Snake river, 26 miles west of Pocatello, Idaho.

The Snake river has here a width of 750 feet, and a break in a lava-flow forms a series of cascades (the American falls) having a drop at low-water of 39.8 feet. As the volume of the flow increases, the difference between the water-levels below and above the falls is somewhat reduced, but from the information obtainable the tail-water will not rise more than 1.5 feet for each foot of increased height in the level of the head-water; and the additional volume of water will more than compensate for the reduced head. It is therefore safe to base estimates of power upon the flow and the fall at low-water stage.

The drainage-basin of the Snake river, above the American falls, approximates 22,000 square miles—equal to one-half the area of the State of Pennsylvania.

Mr. F. H. Newell, Hydrographer of the United States Geological Survey, records stream-measurements made at two points upon the Snake river, one above and one below the

At the Idaho falls (70 miles above the American falls), with a drainage-area of 10,000 square miles, the minimum discharge of the Snake river was found to be 2000 cub. ft. per second in 1890, and 2250 cub. ft. per second in 1892, approximating 0.2 cub. ft. per second per square mile of drainage-area. The elevation of the Idaho falls is 4710 feet, and that of the American falls is 4341 feet, above sea-level. At Montgomery ferry, 25 miles below the American falls, with a drainage-area of 22,600 square miles, the minimum flow was reported as 4420 cub. ft. At each of these stations, the flood-flow exceeds 50,000 cub. ft. per second. Owing to the superposition of lava-benches one upon another, some of the water, following the planes of juncture, appears in numerous large springs, at intervals along the shores of the river, thus affecting estimates of the flow based upon the drainage-area. The investigations made, however, indicate that a minimum flow of over 4100 cub. ft. per second can be depended upon, and that with good water-wheels, properly installed, about 13,000 horse-power can be developed at the American falls with the average low-water discharge.

The locality permits the erection of a power-plant, at small expense, on either side of the river below the railroad-bridge. It is possible, with water-rights granted on both shores of the river, that more satisfactory results may be obtained by dividing the plant, especially for irrigation-purposes; that is, by installing part on the east side of the river and part on the west side; or it may be preferable to connect the eastern shore with a rocky island which divides the river, or to convey electrical energy across the stream by wire.

The fall, being an ordinary one, will require no special form of water-wheels, of pumps or of electric-generators. Hence any development will be relieved from unusual expenditures for equipment, and it will be possible to follow an initial installation capable of meeting immediate requirements by others, as augmented power is demanded, without proportionately increased cost.

A properly-designed plant will raise one cub. ft. of water to the plateau for every 5 cub. ft. applied to the wheels at the American falls; and if a lower lift be found desirable, for placer washings, etc., the proportion of water consumed in this way will be smaller.

Irrigation.—The great stretch of sage-brush plain in south-eastern Idaho, composed largely of decomposed lava, produces, under irrigation, crops of wheat, alfalfa, potatoes, turnips, etc.; and the hardier fruits yield satisfactorily. Large expenditures upon canals and ditches in northern Utah and in Idaho, and the crops obtained from watered lands, testify to the local appreciation of irrigation. The existing installations for irrigation, with few exceptions, withdraw water from the rivers by long feeder-canals, which supply the main and lateral irrigation-ditches.

The territory on the west side of the Snake at the American falls rises quite abruptly to a mesa, or plateau, about 100 feet above the water-level. The eastern side, although ascending more gradually, is cut by draws or ravines, and possesses a more uneven topography. The average descent of the Snake river is about 6 feet per mile, and as a feeder-ditch requires a fall approximating one foot per mile, a main canal 20 miles long would be required to bring water to this plateau, 100 feet above river level.

To avoid this expense, an experimental pumping-plant was erected, consisting of two 23-in. horizontal turbine-wheels, belted to two 32-in centrifugal pumps, having a guaranteed combined capacity of delivering 750 cub. ft of water per minute to the main ditch 104 feet above the river. The wheels, however, utilize but three-fourths of the available fall. The guaranteed capacity of the wheels and pumps as installed (750 cub. ft. per minute) will irrigate 1000 acres.

Auriferous Sand —The existence of free gold in large quantity, but generally finely comminuted (much of it being float-gold) is well known, and the Snake river is actively exploited by dredges and ground-slucing.

The most desirable deposits of auriferous sands are either above the river-level, and therefore unworkable, except by hand-labor or by water artificially elevated, or are in bars in the bed of the stream, from which the sand and the water for washing it must be raised by mechanical power.

Close to the American falls the territory adjoining the shores is worked at a number of places, the material being handled by scrapers drawn by horses, and treated in crude ground-sluices, with satisfactory results. Samples of the con-

centrates were obtained, and also samples, taken over the area excavated, were panned out, showing numerous "colors"

With water delivered to the top of the banks, and used through pipes and nozzles, this territory yields more gold at smaller cost per ounce.

The present operations are confined to bars, or to localities where the stripping is slight, because the material must be handled by animal labor or by steam-dredges, which latter pay from \$4 to \$6 per ton of coal, delivered at the dredges. It is reported that 60 dredges are at work on the Snake river.

Electric power developed at the American falls may possibly be conveyed to operate dredges at other points on the river, at rates which, while profitable to the generating company, will permit a reduction in the cost of operating the dredges.

Three sluice-heads of water, supplied by the 750 cubic feet per minute furnished by the present plant, should each wash at least 500 cubic yards per day when in operation; *i. e.*, they will move 1500 cubic yards per twenty-four hours, and 26 cubic feet of water will therefore be required per cubic foot of material washed. But even if a more liberal supply of water must be pumped, this will permit the moving of the material to sluices at a cost below that required for dredging, and much below that which prevails at the active ground-sluicing operations.

The project is to use the irrigation-ditches for conveying water to the gold-placers, but it may be found advantageous to attack some of the auriferous sands with water which need not be elevated as high as for the ditches, and greater service can thus be secured from a given river-volume, applied as power to pump the water for washing. If, however, gold-washing is carried on as an adjunct to an irrigation-system as planned, there is opportunity for special saving in each department.

A late report of hydraulicking from the end of one of the irrigation-ditches indicates the recovery of gold (.938 to .951 fine) to the value of from 50 to 75 cents per cubic yard of material moved.

All of the gold in the Snake River district is finely comminuted, and the magnetic iron sand associated with it is also quite finely divided.

Iron-Sand.—In the extraction of gold a large amount of this

finely comminuted iron-sand is collected as a by-product; and if this can be obtained free from other sand by supplementing the sluice-work with magnetic-separators, it may be possible to form the material into briquettes and smelt it in blast-furnaces, or it can be converted into iron-sponge by a direct process. Up to the present time, the difficulty of obtaining a uniform product has interfered with the utilization of direct processes, but future advances may make these sands convertible, at present this is not assured. The distribution of the iron-sands is such that the cost of winning them alone will be too great to encourage their utilization; but when obtained as a by-product from gold-washing, it may be possible to convert them into merchantable material

The Lighting and Heating of Pocatello —By railroad, American Falls is 26 miles from Pocatello, but a pole-line can reduce this to about 22 miles, by utilizing a pass.

Pocatello, with a population of 5500, is located in the Fort Hall Indian reservation, and consequently has little near-by farm-land to contribute to its prosperity, but much improvement is expected from the passage by Congress of a bill which provides for the purchase of 100,000 acres of the reservation, tributary to Pocatello, and the opening of it for settlement. This means cultivating the farm-lands and exploiting the mineral deposits.

It is contemplated to utilize a portion of the power available at the American falls to generate electricity, which will be conveyed to Pocatello, and to provide for such industries as may find the use of cheap power desirable at or near the falls. The fact that the railroad crosses the Snake river immediately at the falls gives encouragement to expect such possible utilization of a part of the power

The general scheme is an evidence of the revival of interest in water-power development which characterizes the present time—a revival made possible chiefly by improvements in the design of water-wheels, and in the application of electrical energy to many purposes

The features of this undertaking, now in the initial stage of development, have been described in order to invite attention to the possibilities of other localities which may possess similar advantages

A Peculiar Siliceous Efflorescence upon Pig-Iron.

BY B F FACKENTHAL, JR , RIEGELSVILLE, PA.

(Washington Meeting, February, 1900)

AT the session of the Bethlehem, Pa., meeting of the Institute, held in the Durham Cave, at Durham Furnace, on the afternoon of May 20, 1886, I exhibited some specimens of a fibrous white efflorescence which had exuded from the pig-iron at that time being made at Durham Furnace. As some of the members expressed an interest in the matter, I promised to have complete analyses made, and to report the result in a paper to the Institute. The presentation of the paper has been long delayed, but there appears to be no other literature on this subject, and it may still be of interest.

The efflorescence was found to exude from the pig-iron where the pigs were broken hot from the sow, the entire fracture of both pigs and sow often being entirely coated with this material. Sometimes there was only a white surface, as if the ends had been daubed with white paint; but in most cases the material was found in small globules and in thin sheets. If the iron had been broken a little too hot, and in consequence had "bled" on separating from the sow, some of the efflorescence would be found deposited on the iron-drippings, and on the incrustations of sand in the pig-bed.

The globules were irregular in shape, some of them equivalent in mass to spheres three-eighths of an inch in diameter, but most of them much smaller. The thin sheets were also irregular in shape, and, although they were not porous, were often not thicker than a spider-web. Some of them were produced by the peeling-off of the thin coating on the pigs above referred to. They were opalescent in appearance, and some of them had an area equivalent to two square inches; but the largest pieces would fall apart in handling. Several ounces of the efflorescence could often be picked up, or scraped off the pigs, after each cast.

Analysis of the efflorescence by Dr. P W Shimer gave results as follows

Analysis of Efflorescence upon Pig-Iron.

	Per cent	Per cent
Silica,	94 87	97 67
Oxide of iron,	0 98	1 01
Oxide of manganese,	0 25	0 26
Lime,	None	None
Magnesia,	None	None
Titanic acid,	0 95	0 98
Loss on ignition,	2 87	
Total,	99 92	99 92

The first column shows analysis of the sample after being carefully separated from sand. The second column represents the same sample with the loss by ignition (which was principally graphite) eliminated.

Dr. Shimer also examined the material under the microscope, and observed, besides the radial fibrous efflorescence, occasional cubical crystals of titanium carbide, and some minute hexagonal crystals which he thought were graphite.

The analysis shows that the material is composed of about 95 per cent of silica, and seems to point to the presence, in the pig, of either uncombined silicon or some peculiar silicide.

At the time this efflorescence appeared, the furnace was making Bessemer pig-iron, a careful sampling of which was made during the week ending May 22, 1886, and analyzed by Dr P. W. Shimer as follows.

Analyses of Bessemer Irons.

Elements.	FRACTURE			
	No 2 X	No 2 Plain	Open Gray Forge	Hard Gray Forge
	Per cent	Per cent	Per cent	Per cent
Phosphorus	0 084	0 080	0 079	0 084
Silicon	1 440	1 000	0 840	0 570
Sulphur	0 042	0 068	0 061	0 116
Manganese	0 174	0 173	0 161	0 121
Graphitic carbon	2 970	2 810	2 808	2 520
Combined carbon	1 020	1 200	1 182	1 450
Titanium	0 055	0 027	0 032	0 019
Iron, etc, by difference	94 215	94 642	94 837	95 120
Total	100 000	100 000	100 000	100 000

Dr Shimer found also 0.024 per cent calcium and 0.005 per cent. magnesium in the sample with No 2 X fracture, whether present as metallic alloys or due to intermingled slag has not been determined. The irons with No 2 plain and gray forge fractures were not tested for calcium and magnesium. As the analyses show, the silicon in all grades is low, which was characteristic of all iron made on the mixture of ores used at that time. I have no memorandum to show whether the exudation was the same on all grades of iron, but my recollection is that there was very little, if any, difference. The larger proportion of the iron made was of the softer grades. It is difficult to explain why silicon should liquefy from any pig-iron, particularly one so low in silicon.

These analyses show that the different grades of pig-iron, as determined by the appearance of fracture, contain practically the same amount of graphitic carbon, with varying amounts of silicon. The graphitic carbon in the hard gray forge is particularly high for that grade. The open gray forge (by fracture) was doubtless a softer iron than the No 2 plain (by fracture). This is indicated by the lower sulphur and lower combined carbon, as well as by the higher titanium. It is interesting to note that, as always, the titanium is highest in the softest irons, and (the iron having been made under the same conditions) the graphite follows the silicon, and the combined carbon follows the sulphur.

The ore mixture was made up of $\frac{1}{4}$ Durham Surface, $\frac{1}{2}$ Durham Rattlesnake, $\frac{1}{8}$ Lake Mahopac, N. Y., $\frac{1}{8}$ Elba Lavato, $\frac{1}{16}$ Porman Spanish.

The analyses of the ores, all dried at 212° F., are shown in the table on page 527.

Prof. McCreath writes that he has found from a trace up to 0.105 per cent of arsenic in Porman ore, but has never found more than a trace in Elba Lavato.

The Porman Spanish ore, as the analysis shows, contained 0.568 per cent. of lead. As the mixture contained one-eighth of that ore, the average lead in the ore-mixture was equivalent to 0.071 per cent. This lead was reduced in the furnace, and, being of a heavier specific gravity than the iron, settled on the bottom of the hearth. For a long time no effort was made to collect and save the lead, and it was allowed to run out of the

Analyses of Ores in Blast-Furnace Charge.

Locality	Durham Surface Mine	Durham Rattle- snake Mine	Lake Mahopac, N Y	Elba Lavato	Porman Spanish Average of Several Analyses	Average Analyses of Ore- Mixture
Chemist	P W Shumer	P W Shumer	A S McCreath	A S McCreath		
Iron sesquioxide	Per cent 61 070	Per cent 56 730	Per cent 52 018	Per cent 87 238	Per cent 74 630	Per cent 68 703
Iron protoxide	5 660	11 500	22 885	0 718		7 368
Silica	30 450	25 840	8 780	6 195	8 810	15 526
Lime	0 070	0 160	1 450	0 880	0 420	0 637
Magnesia	0 170	0 820	10 065	0 479	0 130	2 198
Alumina	0 960	2 220	3 078	1 850	1 360	1 843
Phosphoric acid	0 060	0 096	0 028	0 027	0 056	0 048
Sulphur	0 127	0 105	0 014	0 054	0 100	0 077
Titanic acid	0 103	0 300	trace			0 063
Manganese oxide	0 100	0 100	0 186	0 063	1 200	0 242
Alkalies	.	1 010	0 427	.		0 206
Carbonic acid			0 251			0 047
Combined water	1 150	1 000	0 758	2 351	9 680	2 500
Total	99 920	99 881	99 940	99 855	96 386	99 458
Metallic iron	47 150	48 650	54 225	61 625	52 240	53 824
Phosphorus	0 026	0 042	0 012	0 012	0 025	0 021
Sulphur	0 127	0 105	0 014	0 054	0 100	0 077
Manganese	0 063	0 063	0 144	0 044	0 758	0 159
Zinc		.			0 101	0 013
Lead					0 568	0 071
Water, hygroscopic			0 048	7 326	4 747	..
Iron, natural condition				57 110	49 770	52 104

furnace at casting-time, and would become oxidized and sublimated. This could readily be observed by the color of the fumes when casting. At the suggestion of some of the furnace-men, a successful effort was made to save the lead. A few minutes before casting, the tapping-hole was pared quite thin, and as the iron was tapped 8 or 10 inches below the bottom of the iron-trough, a depression was formed, and the lead was allowed to percolate through the thin clay covering at the iron notch into this depression, from which it could be ladled out, a few pounds at a time. The men were paid a half-a-cent a pound for the lead in addition to their wages, and this soon caused a rivalry between the two shifts as to which could produce the most lead. The aggregate lead thus saved before the mixture was changed amounted to about 25 tons. An analysis of the lead, made by Dr. Edward Hart, Easton, Pa., showed that it contained 17.15 oz. of silver to the ton. On blowing out

the furnace, and cleaning it out preparatory to re-lining, it was noticed that considerable metallic lead had found its way into the joints between the courses of brick. This lead was also collected and sold.

During the same blast a ring of cadmia was formed, extending completely around the furnace just below the stock-filling line. After some difficulty in breaking the circle or arch of the ring, it dropped into the furnace-hearth. The lining, where the ring had adhered to it, was left clean, and showed less wear than any other part of the furnace-top. This cadmia was sold to the zinc-works at Jersey City, N. J. It had the following composition

Analysis of Furnace-Cadmia.

	Per cent
Silica,	0 55
Sesquioxide of iron,	1 40
Oxide of zinc,	97 25
Carbon by difference,	0 80
Total,	100 00

The foregoing descriptions and analyses of the charge and products of the furnace have been given here, as elements in the situation as it existed when the mysterious siliceous efflorescence constituting the main subject of this paper was observed. I do not believe that the segregation of metallic lead or the formation of furnace-cadmia was directly connected with that efflorescence; but, on the other hand, so long as the cause of the efflorescence is unknown, it seems wise to place on record all concomitant circumstances which could possibly be related to it.

In closing, I will mention a curious occurrence which does not belong to this case at all, but may be worthy of attention. It was new to me when observed, and I have not seen it, or any description of it, elsewhere. Namely, at the end of one of the earlier blasts at Durham furnace, in removing the red bricks which formed the back-wall next to the shell, and which had been put into place dry, without mortar of any kind, it was found that upon a great many of them amber-colored crystals had been deposited, consisting mostly of pure ammonium chloride. A complete analysis of this deposit was not made; the color may have been due to the presence of iron, or to some organic matter.

The Assay of Copper-Materials for Gold and Silver.

BY L. D. GODSHALL, SPOKANE, WASHINGTON

(Washington Meeting, February, 1900)

THE extreme difficulty of obtaining a short and, at the same time, exact method for the determination of gold and silver in copper-materials has been well illustrated in "Assays of Copper and Copper-Matte," and its discussion, by Dr. A. R. Ledoux and other leading authorities on this subject.*

Two general methods were used by the numerous assayers who took part in the symposium initiated by Dr. Ledoux, and whose results are given in the paper and discussion. One of these is the dry or fire-method, consisting of scorification and cupellation, the former being repeated if the percentage of copper is very high, all slags and cupels being assayed and the results so obtained added to the ordinary assay; and the copper retained by the silver buttons being determined and deducted from the combined weight of the buttons obtained from the assay of the original material, the scorification-slag, and the cupel.

The other is the wet or combination-method, which, while not involving so much work, requires a longer time. Briefly, it is as follows: The material to be assayed is dissolved in nitric acid, the solution is diluted, and the fine undissolved gold is collected by means of sulphate of lead, formed by the addition of lead acetate and sulphuric acid to the solution. After standing from 12 to 24 hours, the precipitate is filtered off, and the silver in the filtrate is precipitated as a chloride or bromide, and collected by means of sulphate or bromide of lead. The solution containing this precipitate in suspension is again allowed to stand until the precipitate has settled. It is then filtered; both precipitates, containing the gold and silver, are dried, ignited and scorified, either separately or together, and the result is cupelled in the usual way.

* *Trans.*, xxiv., 575; xxv., 250, 1000.

The above methods are open to several objections, the most important of which are the amount of work required for the one, and of time for the other. Moreover, the undissolved gold is naturally in an exceedingly fine state of division, the sulphate of lead, though heavy, is a fine precipitate, slow to filter, and, unless care is taken, liable to go through the filter-paper. Again, in case any gold is dissolved, through impurities in the reagents, or from other causes, there are no means of detecting or saving it. In order to overcome these objections, the writer proposes to make use of two reactions, namely, the fractional precipitation by means of H_2S and the reaction between precipitated copper sulphide and a soluble salt of silver.

The method as proposed is, in brief, as follows. Take 0.5 to 4 A. T. of the material to be assayed (the quantity depending on the contents in gold and silver). Dissolve in dilute nitric acid, adding a small quantity of sulphuric acid at the same time. The latter is not absolutely necessary, but facilitates the subsequent removal of the excess of nitric acid. The nitric acid should be added in small quantities at a time, as required, to avoid too violent action, and the use of a large excess. When the solution of the copper is complete, the excess of nitric acid is evaporated, and the remaining solution is allowed to cool, and is then diluted, first with a little cold, then with hot water, and H_2S is passed into the hot solution for a few moments. The exact time has not been determined, but will depend on the contents of silver and the flow of the gas. The idea is to precipitate just enough sulphide of copper to insure the complete precipitation of the silver, and at the same time to collect the very fine undissolved gold. If any of the latter is in solution, the precipitated sulphide of copper will react upon it and render it insoluble. The precipitated sulphides of silver and copper are coarse and flocculent, and settle almost immediately. The fine gold is readily collected by these sulphides; and the solution can be filtered in a very short time. The precipitate is dried on the filter-paper, which is then ignited very gently in a scorifier in front of the muffle, and scorified in the usual way.

The filtrate obtained from the above precipitation can be

tested for silver with a pinch of salt or a drop of HCl, or this may be added at the time H_2S is passed into the solution

The object of all partially wet methods for the assay of gold and silver in the presence of copper is to remove the latter, to avoid the otherwise heavy losses in cupellation. It may be objected to the method here proposed that, after attempting to remove the copper, it again mixes a certain quantity of that metal with the gold and silver. It is evident, however, that the quantity of copper thus added to the gold and silver can be so regulated as to be insignificant in amount, and in nowise to affect the accuracy of the assay.

The advantages of this method seem to the writer to be of considerable importance. The reagents used need not be chemically pure; the time required is but little more than that needed for an ordinary assay, and less care and skill are necessary for the determination than other methods demand.

Further Notes on the Bertrand-Thiel Process.

BY JOSEPH HARTSHORNE, STOWE, PA.

(Washington Meeting, February, 1900)

THE nature of this process and the general course of its development have already been described by me in two papers read before the Institute.*

Since the latter paper was read, in February, 1898, the development at Kladno has been almost altogether in the direction of using metal direct from the blast-furnace. This has now been the regular practice for about a year. The molten metal is brought from the furnace in ladles, without the intervention of any mixing- or accumulating-reservoir.

The plant remains practically the same as originally described by me,† except that the primary furnace has been enlarged as much as was permitted by the existing conditions. This was done primarily in order to increase the capacity of the

* *Trans*, xxvi, 380, xxviii, 254.

† *Trans*, xxvi, 380

plant, by enlarging the limiting factor; but advantage was also taken of the opportunity to change the design of the furnace, by making the hearth as long and wide as possible. By this means the area of surface-contact between the metal and the oxidizing slag was increased, thus increasing the rapidity of the reactions.

I have received recently from Bohemia a detailed report of the operations at Kladno during the latter part of June, 1899. For convenience of reference and study, I have prepared a summary of this report, and preface it with the following general information

The liquid pig-iron, as it came from the blast-furnace, had the following average composition: carbon, 3.5; phosphorus, 1.5; silicon, 1.0; and manganese, 0.4 per cent. The average composition of the metal as it came from the primary furnace was: carbon, 2.4; phosphorus, 0.10 to 0.20 per cent.; and silicon and manganese, a trace. The slag from the primary furnace contained from 20 to 23 per cent. of phosphoric acid and from 7 to 9 per cent. of iron.

The report begins with the first heat of the day-turn of Monday, June 19th, and ends with the day-turn of June 30th. It includes ten and a half working days, or 21 turns, during which time 80 heats were completed. The first heat was made up of solid stock, which was charged cold; but all the other heats were made up of direct metal and cold pig in the primary furnace, and cold scrap in the finishing-furnace.

The term "interval," as used in this report, means the time included between the tapping of one heat and the tapping of the next one in the same furnace, that is, the entire time for a heat, including repairs and charging.

Summary.

Total number of days,	10 5
Total number of turns,	21
Total number of heats,	80
Average number of heats per day,	7 6
Average proportion of liquid pig in the charge,	79 22 per cent.
Average proportion of cold pig in the charge,	6 50 "
Average proportion of cold scrap in the charge,	14.28 "
Average weight of charge in the primary furnace,	12,300 kg
Average weight of charge in the finishing-furnace,	14,350 "
Average total charge, including spiegel, etc,	15,058 "

Average total product, including scrap, . . .	14,989 kg.
Average product of ingots, etc, . . .	14,559 "
Average proportion of ore used in primary furnace,	12 89 per cent
Average proportion of ore used in finishing-furnace,	10 61 "
Average proportion of limestone used in primary furnace, . . .	6 10 "
Average proportion of limestone used in finishing-furnace, . . .	2 61 "
Average interval for primary furnace, . . .	3h 0 15 m
Average interval for finishing-furnace, . . .	3h 0 10 m
Average time metal remained in primary furnace,	1h 57 70 m
Average time finishing-furnace was empty, . . .	1h 2 30 m

Stock Account.

Total charge, including spiegel, etc, . . .	1,204,630 kg	
Total product, including scrap, . . .	1,199,134 kg	99 54 p c
Total loss,	5,496 kg	0 46 p c

Ingot Account

Total charge, including spiegel, etc, . . .	1,204,630 kg	
Total product of ingots, etc, . . .	1,164,738 kg.	96 69 p c
Loss to ingots,	39,892 kg	3 31 p. c

The iron of the ore is not included in the weight of metal charged. About 1 per cent. of scrap is recovered from the slag, mostly in the form of shot, but this is not included in the amount of scrap shown in the above account.

The time the charge remains in the furnaces being so nearly the same for each, the limiting factor of the plant is the size of the smaller furnace, which, in this case, is the primary one. The general result of the operations covered by the report summarized is, that an average of 7.6 heats per day, averaging 14,559 kg. each, or a total of 110.65 metric tons, was obtained from a pair of furnaces, the limiting one of which had a capacity of about 13 tons. This product was made with a total loss of 0.46 per cent and a loss to ingots of 3.31 per cent. The finishing-furnace was empty for about one-third of the time, averaging one hour and two minutes to a heat; but a part of this time was, of course, taken up by the repairs. These repairs were, however, very light.

Since the end of June the work has been carried on upon the same lines, with a slight but decided increase both in number and weight of heats per day. The last detailed report re-

ceived up to the time of this writing was for the week ending December 9, 1899. The actual time of working was forty-five minutes less than a full week of six days. The following is a summary of the operations for this week. It is not given in such detail as the one for June, since the general features are practically the same.

Summary of Report for the Week Ending December 9, 1899.

Total time occupied,	.	.	5 d, 23 h, 15 m
Total number of heats,	.	.	48
Average number of heats per day,	.	.	8
Average weight of ingots per heat,	.	.	15,220 kg
Average daily product of ingots,	.	.	121,760 "
Total product of ingots for the week,	.	.	730,670 "
Total amount of ore charged,	.	.	184,530 "
Total amount of limestone charged,	.	.	70,290 "

Stock Account

Pig, liquid,	.	.	.	571,190 kg = 79.76 per cent.
Pig, cold,	.	.	.	73,390 " = 10.25 "
Old rolls,	.	.	.	16,290 " = 2.27 "
Scrap,	.	.	.	55,280 " = 7.72 "
Total,				716,150 kg = 100.00 per cent
Spiegel,	.	.	.	8,480 " = 1.18 "
Ferro-manganese,	.	.	.	10,400 " = 1.45 "
Total,				735,030 kg.
Total product,	.	.	.	748,560 "
Total gain,				13,530 kg = 1.84 per cent.

Ingot Account

Total metal charged,	.	.	.	735,030 kg
Total ingots, etc,	.	.	.	730,670 " = 99.40 per cent.
Loss to ingots,				4,360 kg = 0.60 per cent
Amount of slag from primary furnace,	.	.	.	81,600 kg

This shows an average daily product of 8 heats, each weighing 15,220 kg, or a total of 121,760 kg., with a total gain for the week of 1.84 per cent. and an ingot-product of 99.40 per cent. The ore used is Gellivara, containing about 67.0 per cent. of iron. These results are the more remarkable, when it is remembered that the charges were made up of from 85 to 90 per cent. of pig-iron, containing 1.5 per cent. of phosphorus and 1.0 per cent. of silicon.

Since the oxidizable impurities of the bath, which make up the unavoidable loss, amounted to 6.4 per cent, and an absolute gain of 1.84 per cent. was made, there must have been at least 8.25 per cent of iron reduced from the ore. If we add to this the 1 per cent of shot in the slag, and remember that there is always a certain amount of the iron of the charge which is oxidized (amounting to from 2 to 4 per cent. in the ordinary open-hearth process), it is safe to say that an amount of iron was reduced from the slag equal to at least 11 to 12 per cent. of the metal charged. This, of course, is merely a rough calculation (several of the minor factors being ignored), and, while interesting, is not of so much importance as the fact that an absolute gain of 1.84 per cent. was made with an ingot-product of 99.4 per cent. The average for the month of December was 102 kg. of total product for every 100 kg. of metal charged, with an ingot-product of 98.2 per cent.

The production of 81.6 metric tons of slag, containing from 20 to 23 per cent of phosphoric acid, is a factor not yet so important in this country as in Europe, where between 400,000 and 500,000 tons of basic slag per year are used as a fertilizer. With proper efforts, however, the great value of this material must eventually be appreciated by our farmers, and a good market obtained for it.

On page 261 of vol. xxviii. of the *Transactions* I have given summaries of the deductions which, it seemed to me, were to be drawn from the experience up to that time. These deductions have been practically substantiated by the results of the subsequent operations at Kladno; but there are two modifications which should be made in the section (3) on that page relating to the use of direct metal. The later results have shown that the two furnaces, constituting the unit of a plant for the use of direct metal, should be of the *same* size, or, rather, capacity, and that the weight of the heat is determined by the capacity of the smaller one, should there happen to be any difference between them.

In a plant which is built on different levels, as at Kladno, and in which the metal runs from one furnace to the other by means of a trough, the upper furnace is always the primary, and the lower furnace the finishing, one. Where the furnaces

are all on one level and the primary metal is transferred by means of ladles, each furnace may be either a primary or a finishing one, as circumstances may determine. In the first case, where each furnace is always used for the same purpose, a certain advantage may be gained by modifying the design to suit the special function intended. It would then be better that the primary furnace should have a hearth with as large an area as possible, thus giving a shallow bath, with great surface-contact between the metal and the slag. This will shorten the operation by hastening the reactions, and, at the same time, will somewhat reduce the repairs. The finishing-furnace should have a deeper bath, in order to lessen the danger of oxidizing the metal.

When all the furnaces are likely to be used for either purpose, this difference in form cannot be taken advantage of, and the furnaces should be designed to suit the finishing part of the process. In my opinion, the loss of time due to the use of a deeper bath in the primary furnace would be much more than made up by the greater simplicity, convenience and flexibility of the plant.

In conclusion, I would again point out that this process is exceedingly advantageous for those localities where scrap is scarce and dear, and large quantities of pig-iron, high in silicon or phosphorus, or in both, have to be used. This has lately been shown again in an extended series of experiments made in an English plant. The detailed results of these experiments have not yet reached me, but, among other things, they showed that a pig-iron containing from 2.75 to 3 per cent. of phosphorus and comparatively high silicon could be used without lengthening the process. The arrangements for making these trials were somewhat imperfect, as compared with a plant designed for the particular purpose, but the results were practically the same as those obtained at Kladno.

The Oil-Bearing Shales of the Coast of Brazil.

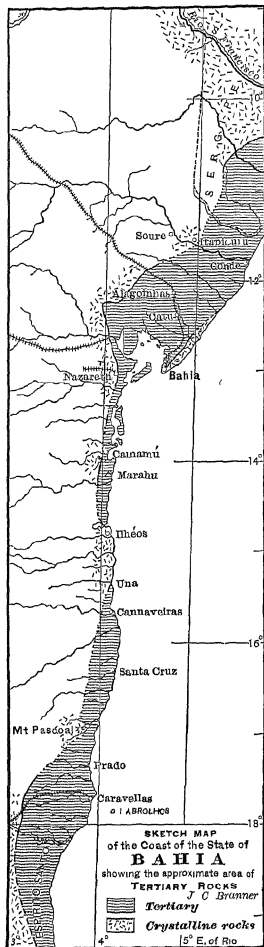
BY JOHN C. BRANNER, STANFORD UNIVERSITY, CAL.

(Canadian Meeting, August, 1900)

SHALES rich in oil are found at several places along the coast of Brazil. The material has been prospected at several places, and samples have been examined and reported upon by competent authorities. So far as I am acquainted with them, these oil-bearing beds are of Tertiary age. A glimpse at the distribution and character of the Tertiary rocks of the region should give us some idea of the possible distribution of these oil-bearing shales. Tertiary rocks skirt the northeast coast of Brazil from the northern part of the State of Espírito Santo almost or quite to the Amazon valley. Here and there this narrow strip is cut in two by the encroachment of the sea, and the underlying gneisses, granites or other crystalline rocks are exposed upon the beach. In other places, the Tertiary belt widens out until it is 80 kilometers or more in width. Fig. 1 is a sketch-map of a part of the coast-area referred to.

Along the coast from Prado, in the State of Bahia, northward to Natal, there is a line of bluffs from 15 to 90 meters high, interrupted here and there by stream-valleys. As seen from the sea, these bluffs are rather conspicuous and highly colored yellow, brown, red, white, black, and purple. These colors are often so mingled as to give the beds a mottled or parti-colored appearance. Fig. 2 shows a characteristic bit of the coast in the State of Parahyba do Norte. In some places, especially in the southern part of the State of Sergipe, and in the northern part of Rio Grande do Norte, the immediate coast is covered with sand-dunes. Here and there these sand-dunes have been carried inland over the top of the Tertiary beds, and the subsequent encroachment of the sea has exposed the Tertiary rocks again, where they form the bases of the bluffs. This is well shown in Fig. 3, from a photograph taken at Bahia Formosa, on the coast of Rio Grande do Norte.

FIG. 1



The width of the Tertiary belt has been determined at several places. Owing partly to the fact that the landward margin of the beds is generally more or less ragged, and partly to the lack of good maps, these measurements must be accepted as only approximately correct.

1. From Porto Alegre, just south of Caravellas in southern Bahia, along the Rio Mucury to the Serra dos Aymores, 80 kilometers. This does not include the Abrolhos islands of the coast, which are also Eocene Tertiary.

2. At Ilhéos, Bahia, there are no sedimentary beds; the crystalline rocks appear on the shore.

3. At Camamu, 22 kilometers.

4. From Bahia to the western margin of the series near Nazareth, 50 kilometers.

5. From Bahia in the direction of Feira de Santa Anna, 82 kilometers.

6. Across the axis of the basin at Alagoinhas, Bahia, 80 kilometers.

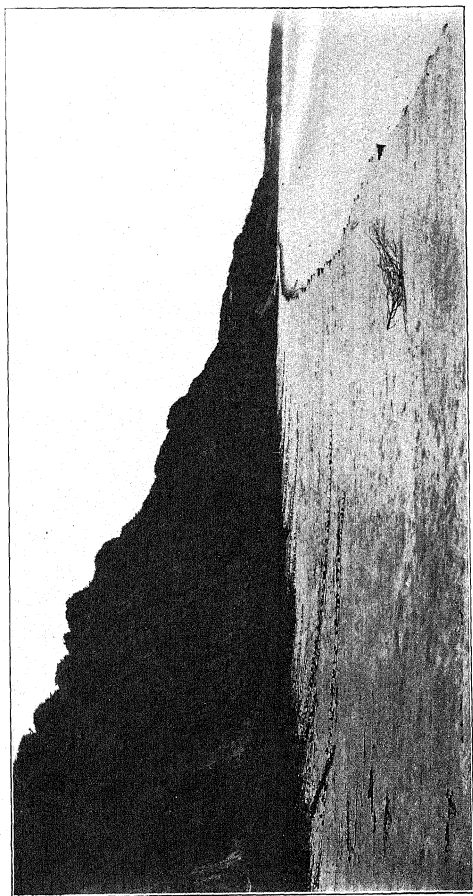
7. From Aracajú to the Serra d'Itabaianinha, 80 kilometers.

8. Along the Rio São Francisco from its mouth to Proprá, 60 kilometers.

9. From Maccio to Cachoeira along the Alagôas railway, 33 kilometers.

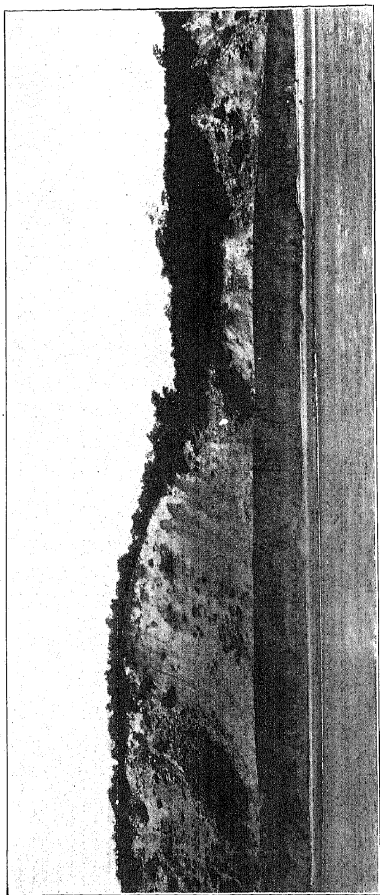
10. At Pedra do Conde,

FIG. 2.



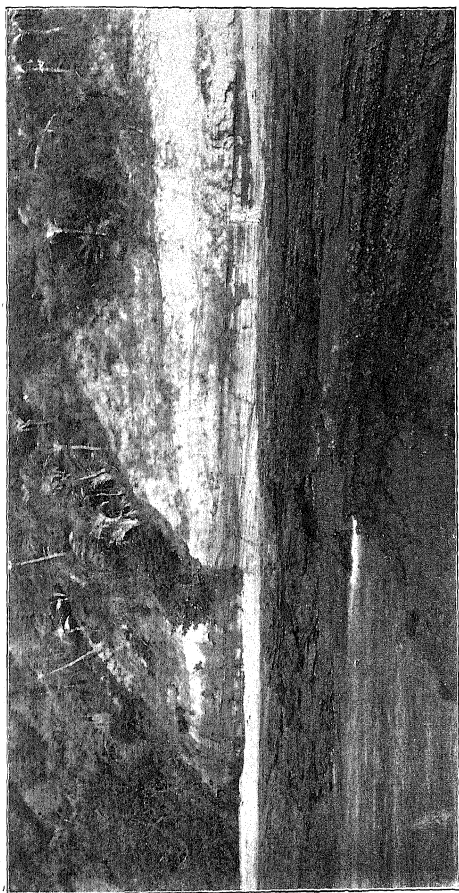
The Red and Mottled Cliffs, 3 kilom. N. of Trairão, State of Paraíba do Norte.

FIG. 3.



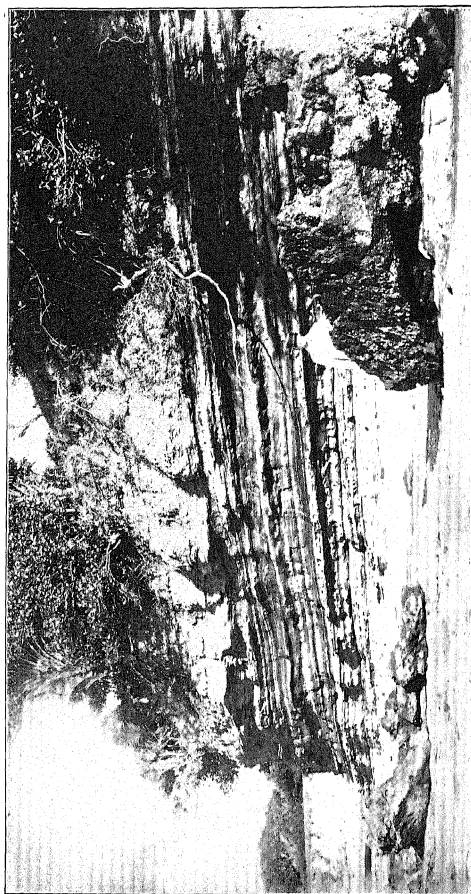
Bluffs, 200 feet High, Capped with Sand, at Bahia Formosa, State of Rio Grande do Norte.

FIG. 4.



The Gray Unaltered Sediments at the Base of Morro de Camaragibe, Merging into the Highly-Colored Beds of the Hill-Tops.
Wave-Cut Terrace of Oil-Shales in the Foreground.

FIG. 5.



The Oil-Shales, 2 kilom. South of Morro de Camaragibe.

south of Tamandaré, 0 kilometers; granite is exposed on the beach.

11 At the mouth of Rio Formoso, State of Pernambuco, 3 kilometers

12. At Cape Santo Agostinho, Pernambuco, 0 kilometers; granites and porphyries on the beach.

13. At Pernambuco along the Great Western of Brazil railway, the granite is exposed $\frac{1}{2}$ kilometer above Macacos; 7 kilometers.

14 On the Central de Pernambuco railway the inland margin of the Tertiary is about kilometer 10, two kilometers above Tigipió. On the Recife ao São Francisco railway the Tertiary beds are not exposed, the first recognizable beds being crystalline rocks at Cabo, kilometer 31.

15 At Parahyba do Norte on the Conde d'Eu railway, 30 kilometers.

16. At the Rio Grande do Norte the Natal a Nova Cruz railway does not cut square across the Tertiary, but runs southward parallel with the coast and on Tertiary beds for most of its length. It crosses the Matahú river on the gneiss, so that the Tertiary varies in width here from 15 to 50 kilometers

At Bahia, Tertiary beds are let down by a fault behind a narrow strip of crystalline rock which, northeast of that city for many kilometers, separates them from the ocean.

In my work upon the stone and coral reefs of Brazil, a trip was made on foot along the beach from Pernambuco to Maceio, in the State of Alagôas. This trip afforded an excellent opportunity for seeing the best exposures of these rocks to be found in the country.

The series to which the oil-shales belong is exposed in many places about Cape Santo Agostinho, Rio Formoso, Tamandaré, Abreu de Una and Maragogý, but at these places the unweathered shales were not found.

Going south from Pernambuco, the oil-bearing shales were first found upon the beach just south of the mouth of Rio Maragogý, 9° 3' S. latitude, in the State of Alagôas. At this place they are uncovered at low tide and extend seaward for a few hundred meters, forming a wave-cut bench. They are also exposed in the bank above the reach of high tide. The beds are more or less wrinkled, and a small syncline is plainly shown

upon the bench at low tide. The dips observed are 10° S. 71° W., and 6° S. 31° W., magnetic. The shales all dip landward and beneath the red and mottled beds exposed in the cliffs or line of hills that follow along close to and parallel with the coast at this place.

Between the mouth of Rio Maragogý and the village of São Bento, at a *venda* called Camáxo, the sea has cut into a bed of heavy conglomerate rocks that underlie the shale beds. Immediately south of these conglomerates, black shales are exposed at low water. These shales contain many finely broken plant-remains. The dips of the shales at this locality vary as follows 9° S. 60° W., 4° S. 80° W., 4° S. 33° W., 10° S. 50° W., all magnetic.

It is noticeable in all these cases that the dips carry the rocks downward toward the hills that follow the coast-line.

At Japaratubá, just south of the mouth of a small stream, low tide exposes conglomerates, sandstones and shales, dipping S. 80° W. The exposure extends seaward about 300 meters from the beach.

In front of Pitinguí ($9^{\circ} 7'$ S lat.) shales are exposed at low tide dipping 9° N. 70° W and 7° due west. Just north of Pitinguí, however, a red cliff rises to an elevation of something like 90 meters.

There is another interesting exposure of the shales at a place called Barreira do Boqueirão, between one and two leagues north of Porto das Pedras. Here the sea has cut into the foot of one of the red hills and has exposed about 7 meters of mottled, gray and red sandstones. The shale is visible to the south of this exposure, partly covered by soil and vegetation from the hills above. The shale where exposed is about 2 meters thick, but it is possible that it has a thickness of 3 or 4 meters. Along the shore the exposure is about 100 or 150 meters long. The dip varies considerably both in amount (10° to 15°) and direction, but for the most part the dip is inland and toward the red hills of the coast. The hills above this particular place are about 60 meters high.

At the mouth of the Rio Mangnába (sometimes called Rio Porto Calvo), in the edge of the town of Porto das Pedras (S. lat. $9^{\circ} 10'$), these beds are exposed again at the ferry. Here the rocks are mostly sandstones; but they are of the same

series, and the shales are interbedded with them. The dip is southwest about 3° or 4° .

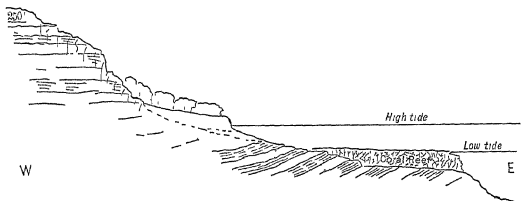
In the bottom of the embayment south of Marcenerio, the shales are exposed at low water, with a coral reef overlapping them, as shown in the section, Fig. 6

The dips observed are 10° N. 39° W., and 13° N. 57° W., magnetic; about 185 meters south of this place the dip is 12° N. 25° W.

At the Barra do Passo or Barra do Camaragibe there is one set of exposures north of the mouth of the river off the town, and another a league south of there at a place called Morro de Camaragibe or Barreira do Morro.

On the beach in front of the town of Barra the shales dip inland toward the town at an angle of from 70° to 10° , and

FIG. 6.



Geological Section at the Bottom of the Embayment S of Marcenerio, Showing the Shales Dipping Landward and Overgrown with Coral-Reefs

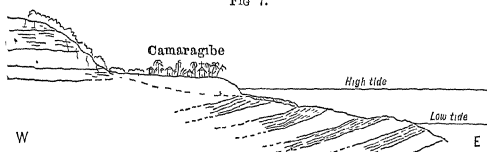
plunge beneath the hills back of the town. A section at this place would be something like Fig. 7.

The exposures on the cape just south of the Camaragibe at the Barreira or Morro de Camaragibe are unusually good, especially at low tide.

The cliffs are from 75 to 90 meters high. The upper beds are the well-known red, yellow and mottled beds of the coast; while at the base of the bluffs and uncovered at low tide are the shales and sandstones dipping landward. The lower beds form a wave-cut terrace about 150 meters wide. At the northern exposure of the bluffs on the beach are many large boulders of pink granite, apparently washed from a basal conglomerate underlying the series exposed on the hills. Some of these

water-worn granite boulders (see Fig. 8) are about a meter in diameter. The sandstones at the base of the bluff contain also rolled lumps of clay. The angle of the dip of the beds is usually low (from 5° to 10°). Several pits have been sunk about and south of the cape by an English company that

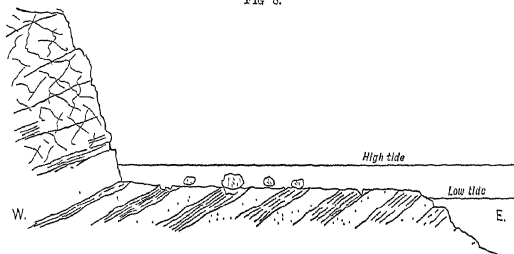
FIG 7.



Section through Passo de Camaragibe, Showing the Shales Exposed Between Tides, and their Relation to the Mottled Beds in the Hills back of the Town

prospected these shales some 10 or 12 years ago. Many of the shale beds contain large quantities of fragments of plants, so finely pulverized that no recognizable forms were found. The exposures in the bluffs here show in a satisfactory manner that the mottled and highly-colored beds exposed in the cliffs

FIG 8.



Section at the Morro de Camaragibe, Showing Wave-Cut Shelf of Shales, with Boulders of Granite. Dip somewhat exaggerated.

along this coast are the weathered parts of the Eocene beds.

Fig. 4 is from a photograph taken from the wave-cut platform of shales on the seaward side of the hill. The beds shown in this picture have a marked dip, and the portions of the rock at the base of the hill are gray and unaffected by

the weather. Following the beds with the eye, one can trace many of the strata high up into the mottled and parti-colored beds that form the tops of the hills. To one near at hand, the transition from the unweathered to the weathered beds seems to be very gradual; but to one standing a hundred meters away from the face of the bluff there seems to be a well-defined line of demarkation between the gray beds below and the highly-colored ones above. This coloration affects all the rocks of the top of the bluff down to an elevation of about 4 or 5 meters above tide-level. In the observations made on the spot I find this note "I see absolutely no difference between this cliff and hundreds of others I have set down as Tertiary"

The company that prospected this locality for oil-shales sank 6 pits south of the village of Barreira, one of which was 6 meters deep. The following are the determinations made by Mr. Boverton Redwood of the composition of the shales taken from the pits at this place

Composition of the Camaragibe Shales

Volatile Per cent	Non-volatile Combustible Per cent	Ash Per cent
30.55	9.45	60.0
24.8	4.3	70.9
27.1	12.2	60.7
25.5	2.2	72.3
7.8	2.9	89.3

Two kilometers south of the village of Barreira the shales form a wave-cut terrace, and the beds dip west at an angle of 10°. (See Fig. 5.)

Going south from this locality there are several kilometers of the red and mottled cliffs before one reaches the Barra de Santo Antonio. These cliffs are the beds above the oil-shales, or the weathered portions of the oil-shales themselves.

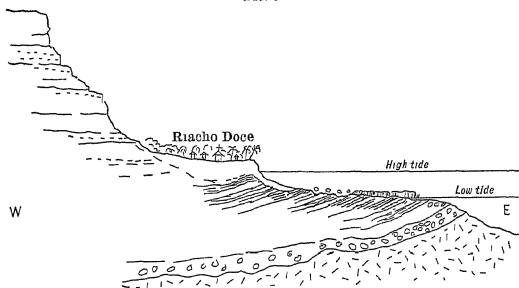
The bluffs are about 30 meters high, and the colors are variegated and most brilliant. Seen from a distance, the colors seem to be due to the bedding of the rocks; but upon examination close at hand they are found to be due partly to structure and partly to weathering.

The next considerable exposures of the oil-shales south of Santo Antonio Grande are at Riacho Doce (S. lat. 9° 36'), and

between that stream and another small one known as Garça Torta.

The exposures at Riacho Doce are very much like the others mentioned above. Inland about half a kilometer from the beach is a steep-faced escarpment, 60 to 90 meters high, of highly colored beds; while on the beach itself are exposed shales, sandstones, and heavy conglomerates, containing large granite blocks. The dips taken on the beach at low tide vary considerably, showing that the rocks here have been much wrinkled. I noted also some faults and overthrusts. The general structure can best be shown by a section, such as is given in Fig. 9, which would answer for almost every one of the

FIG. 9



Section at Riacho Doce, Showing the Relations of the Shales to the Conglomerates, and to the Cliffs West of the Village

exposures seen. The heavy granite blocks indicate the near presence, at almost all of the exposures, of the granite which underlies them. The shales all overlie the heavy granite conglomerates.

The only fossils found in these rocks thus far are diatoms, plant-fragments and fish-remains. The diatoms so far as examined have no diagnostic value further than to show that the beds are of fresh-water origin, while the other plant-remains are so fragmentary as to be unrecognizable. The fish-remains have been kindly examined for me by Prof. F. A. Lucas of the U. S. National Museum, who finds them to belong to the genus *Diplomystus*—a genus already reported from the fresh-water

Eocene beds of Bahia,* where the fossils were collected by Mr. Joseph Mawson at Itacaranhã, Plataforma, and Água Comprida.

A section made across country from the coast inland at almost any point shows the same geology, with only local variations. In some places the shales are thicker, in others they are entirely wanting.

The same company that prospected the oil-shales south of the Rio Camaragibe has dug several pits near the beach at Riacho Doce also. Boverton Redwood found the shales from this place to be richer in oil than those of Camaragibe district. The following table is taken from his report upon them †

Composition of the Riacho Doce Shales.

No	Volatiles Per cent	Non-Volatile Combustible Per cent	Ash Per cent
1	34.9	1.1	64.0
2	46.3	19.5	34.2
3	26.9	8.1	65.0
4	32.8	14.6	52.6
5	25.4	10.5	64.1

A further examination was made by Mr. Redwood of the richest of these shales (No 2). This contained 4.7 per cent of sulphur, and upon distillation yielded 44.73 gallons of crude oil and 19.58 gallons of ammoniacal water to the ton. Mr. Redwood says further, in regard to these oil-shales

"The presence of sulphur would not, however, be a serious drawback, if the crude oil were used as a liquid fuel, or as a source of gas for illuminating purposes. One ton of such oil would, if properly burned, afford rather more heat than two tons of good steam coal, and from each gallon of oil about 90 cubic feet of 60-candle gas could be produced.

"As regards the quality of the crude oil, it should be remarked that results obtained on the laboratory-scale of working are less satisfactory than those yielded when the shale is distilled on the manufacturing-scale in retorts of suitable construction. The difference is far greater in the case of the ammoniacal liquor, and a yield of probably as much as four times the quantity of sulphate of ammonia may be reckoned upon."

* "On two deep-bodied species of the clupeoid genus *Diplomystus*." By A. Smith Woodward. *Annals and Magazine of Natural History*, Jan., 1895, pp. 1-2.
 "A Contribution to the Vertebrate Paleontology of Brazil." By E. D. Cope. *Proc. Amer. Phil. Soc.*, Jan., 1886, xxiii, 3-4.

† *Report on the Riacho Doce and Camaragibe Shale Deposits on the Coast of Brazil, near Mucio.* By Boverton Redwood and William Topley. (London, 1891.)

The parti-colored beds follow the coast southward from Riacho Doce to the city of Maceio and beyond.

At Maceio the lighthouse stands upon the summit of this same Tertiary plateau. The beds exposed in and about the city are all more or less mottled, and along the line of the railway that runs westward between the lake and the hills these strata are cut at several places. No fossils were found in these rocks either at Maceio or along the line of the Alagôas railway. At the Instituto Archeologico e Geographico Alagoano, Dr. Costa Leite, the Secretary, showed me two fossil fishes, said to have been found at Fernão Velho, 14 kilometers from Maceio. The rock containing these fossils is a limestone concretion closely resembling that in which the fossil fishes of Ceará are found. Although the rocks at the base of the hills at Fernão Velho are yellow, cream-colored, and gray, that is, not so highly colored as the beds further up the hills, I am disposed to think that no importance should be attached to the reported origin of these fossils. The Ceará fishes have been carried all over Brazil, as curiosities; and it is quite possible that these specimens came from the Ceará beds, and, through some accident, have appeared at Fernão Velho, or have been reported from there by mistake.

The Tertiary series is crossed almost at right angles by the Alagôas railway. About a kilometer and a half east of Utinga station gray shales like those of Riacho Doce are exposed by the side of the railway. At several places along the line between Fernão Velho and Albuquerque are heavy beds of water-worn crystalline rocks, which I take to be the basal conglomerates of the Tertiary series. One of these exposures is immediately east of Cachoeira, where the conglomerate bed is about 10 meters thick. At kilometer 33 between Cachoeira and Albuquerque, the next station, the sedimentary series ends, and the railway west of these runs over granites and other crystalline rocks only. One cannot fail to observe the similarity of all these sections across the Tertiary, so far as their main features are concerned, though this one from Maceio to Albuquerque is much longer than the others.

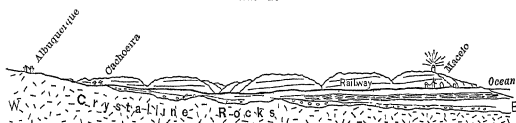
Fig. 10 is an ideal section on the Alagôas railway. South of Maceio the Eocene beds are exposed about the shores of Lagoa Manguaba, on Rio Jiquiá and on Rio Cururipe, but I

do not know the western limits of the series in that direction except near the Rio São Francisco

Where the shales are exposed about the east side of the Bay of Bahia they bear the strongest possible resemblance to the oil-bearing shales of Alagôas. I am not aware of any examination or attempted working of the oil-shales near the city of Bahia or on the island of Itaparica. Turfa beds, however, are reported from the northern part of the island of Tinharé, 40 kilometers south of Bahia, and from Rio Itahipe in south latitude $14^{\circ} 44'$ +

The turfa beds on Rio Marahú, just south of the Bay of Camamú, and 115 kilometers south of the city of Bahia, have been known for many years, and the material has been much less talked about in Brazil. Hartt says of this turfa †

FIG 10



Ideal Section from Maceio to Albuquerque along the Alagôas Railway (35 kilom.), Showing the Eocene Sediments Overlying the Crystalline Rocks

"The material burned readily when ignited in a candle, affording an abundant smoky flame. The material appears to be merely a mud impregnated with bitumen, and as it appears to exist in large quantities, it would be very valuable for gas-making or the manufacture of kerosene."

Hartt quotes from Mr. Nicolay to the effect that the Camamú series does not appear to be in any way connected with that of Bahia or with those of the south, unless, as has been reported, turfa is found in the Rio de Contas. This series, it is said, may be designated as follows.

"In a basin of gneissose rocks are bituminous schists, sands and marls containing fossils (fresh-water?), and, it is presumable, above that, the turfa."

* Henrique Pragues in the Revista do Instituto Geographico da Bahia, vol iv, p. 429.

† *Geology and Physical Geography of Brazil*, by Chas. Fred. Hartt, Boston, 1870, pp. 263-4. In quoting Hartt I have substituted *turfa*, the word used by the Brazilians, for the *turba* erroneously used by him.

Mr. Nicolay gives the following section of a shaft put down in the turfa district.*

Section of Shaft in Turfa District.

Ft	In	
20	0	Clayey and sandy shales
3	0	Bituminous clay
4	0	Ferruginous sandstone
0	9	Shale with lignite
0	9	Bituminous stratum
1	6	Micaceous shale
1	6	Shale with lignite and bitumen
2	6	Shaly strata
2	0	Bituminous strata
12	0	Shaly rocks
15	0	Bituminous strata
45	0	Gneissose rocks
<hr/> 108	<hr/> 0	

Within a few years the oil-shale deposits of Marahú passed into the hands of a company controlling abundant means, and the most extravagant preparations were made to manufacture soap, paraffine, various kinds of oils, and I know not what. A town was built about the extensive factories, vast quantities of expensive machinery and supplies of every kind were imported from England, and the establishment started operations on a scale out of all proportion to the possibilities of the market. As might have been expected, the whole business collapsed within a few months, and much of the machinery is now rusting in the mud of the mangrove swamps, and the empty houses are being devoured by white ants. I believe this is the only effort that has been made to utilize the oil-bearing shales of Brazil. It is to be regretted that the business was not conducted in a more conservative manner, for after so colossal a failure other companies will hesitate to embark in any enterprise that attempts to utilize the oil-shales of Brazil.

It is worth noting, however, that the Brazilian government affords all the "protection" that any industry can reasonably ask in the way of high import-duties, and if it is found that these shales can be utilized, import-duties will be freely laid upon all the products that can be made from them.

* In giving this section I have altered the wording somewhat to express the evident meaning of Mr. Nicolay; he uses the words *schist* and *schistose* where *shale* and *shaly* are meant.

Résumé—The oil-shales of the Brazilian coast are of Tertiary age, and the parti-colored beds exposed in the bluffs along that coast are for the most part the weathered portions of this same series. The Tertiary strata rest upon granites, gneisses and other crystalline rocks, with a bed of very coarse conglomerates forming the base of the series. The only known exception to this is in the Serra d'Itabaiana, in the State of Sergipe, where there is a series of Cretaceous beds with older beds between the granites and the Cretaceous, that appear to be Paleozoic, though no fossils have been found in them. The failure of the Marahú Company was evidently due to extravagance and mismanagement, and cannot be regarded as a sufficient reason for condemning the oil-shales of Brazil as unworkable.

The total thickness of the Tertiary beds does not much exceed the total thickness of the mottled and parti-colored beds exposed on the coast—that is, from 30 to 90 meters (100 to 300 feet). This is shown by the fact that at many places the basal conglomerates are exposed, while at several points the crystalline rocks themselves are uncovered.

No oil-shales are now known in Pernambuco, Parahyba, Rio Grande do Norte, Sergipe or Espírito Santo, but they may be expected in any of those States within the Tertiary area.

POSTSCRIPT.

WHEN this paper was sent to the Secretary the oil-bearing beds referred to were set down as Cretaceous, and they are so classified in the pamphlet edition. This was done because the sediments of the Bahia basin had been accepted as Cretaceous without question since the publication of Hartt's book* in 1870. An examination of the paleontologic evidence, however, fails to reveal any satisfactory reason for this correlation. There are true Cretaceous beds in the State of Sergipe, just north of Bahia, but they are marine deposits, with a rich fossil fauna, and are not connected with the fresh-water beds of the Bahia basin. The marine sediments at Pernambuco, Maria Farinha, Itamaracá, Parahyba, Piabas, and other intermediate points along the coast, which were supposed to be Cretaceous,

* "Geology and Physical Geography of Brazil," by C. F. Hartt, Boston, 1870.

turn out to be Eocene Tertiary. Upon this subject I have asked the views of Dr Gilbert D Harris, of Cornell University, one of our best authorities on the Eocene, who writes

"I can assure you most emphatically that neither in that work [Dr White's report upon the Brazilian Mesozoic fossils], nor in our specimens [at Cornell University], nor in those I have seen in the United States National Museum from Maria Farinha, can I find a trace of any fauna other than the Midway Eocene "

An examination in 1899 of the geology of the coast, from Natal, State of Rio Grande do Norte, to the southern part of the State of Bahia, led me to the conclusion that the highly-colored beds of the coast (Pernambuco, Maria Farinha, Parahyba, Alagôas, etc.) were approximately of the same age as the fresh-water beds of the Bahia basin. If this is correct, then the Bahia basin is Eocene Tertiary, instead of Cretaceous. In calling them Tertiary, however, we are but going back to their earlier classification by Darwin[†] in 1841, by Pissis in 1842,[‡] and to the age suggested by the *Entomostraca* described from Bahia by Professor T. Rupert Jones, in 1859.[§]

The requisite corrections have been accordingly made in the text of the pamphlet edition of this paper, before the present republication of it

Experiments Regarding the Influence of Silica on the Loss of Silver in Scorification. §

BY LESTER STRAUSS, NEW YORK CITY

(Canadian Meeting, August, 1900)

THE fact that the loss of silver in the slag of the smelting-process increases with the amount of silica in the furnace-charge, was probably the ground of a general opinion that the silver is present in the slag as a silicate. Dr. Hies, in his inter-

* "Geological Observations," by Charles Darwin, 2d ed., p. 193, London, 1876.

† *Mém sur la position géologique des terrains de la partie australe du Brésil*, etc., par M. A. Pissis (Présenté à l'Académie des Sciences, le 27 Juin, 1842)

‡ *Quar Jour Geol Soc*, December 14, 1859, xvi, 266-268

§ This paper constitutes in substance No. 34 of the "Contributions from the Havemeyer Laboratories," Columbia University

esting experiments upon the slags of scorification,* found in no instance any silicate of silver. These experiments, however, were made with pure crystals of AgNO_3 —a circumstance which may have affected their results, since it is conceivable that an intimate mixture of metallic silver with silica might more strongly favor the formation of a silicate. Fusing at a low heat for three hours, and then allowing to cool, 6.8 grammes of AgNO_3 with 1.2 grammes of pure anhydrous SiO_2 (these proportions corresponding to the equation, $2\text{AgNO}_3 + \text{SiO}_2 = \text{Ag}_2\text{SiO}_3 + \text{N}_2\text{O}_2 + \text{O}_2$), Dr. Hies obtained a bright brick-red slag, the color of which was due to Ag_2O .

The only other experiments of interest bearing upon this subject are the crucible-assays reported by Mr. Furman,† of which Nos. A1 and A2 have special interest. In these instances, he assayed 108.15 and 102.75 mg of silver with $\frac{1}{2}$ A. T. of SiO_2 , and found the losses to be 2.47 and 1.93 per cent., respectively. These are small losses. With low-grade ores, Mr. Dewey‡ found the loss higher, as was also the result in the experiments described below. Mr. Furman assayed also 116 mg of silver with 7.5 grammes of SiO_2 and 7 grammes of FeS , and found the loss of silver to be 4.66 per cent. This is smaller than the losses (5.2 and 5.3 per cent.) shown by Experiment No. 4, described below, in which SiO_2 and FeS were ingredients. It would seem that, in an assay of silver with silica, the presence of a sulphide of iron tends to keep the loss of silver nearly constant.

In order to test the influence of silica in the scorification-assay, the following experiments were made.

In these experiments pure ores (pyrite, zincblende, galena or stibnite), sulphur, silica and test-lead—all free from silver—were mixed with filings of silver, 0.992 fine and free from iron. No borax-glass was added, since it was desired to avoid, as far as possible, the introduction of factors which might affect the result. In all cases (with two exceptions) the temperature of scorification was between 900° and 1000°C . The cupellations were made with “feathers.”

* *Eng and Min Jour.*, April 19, 1884, vol. xxxvii, p. 297.

† *Trans.*, xxiv, 741. Mr. Furman reports the amount of silver, etc., in “parts”—each part representing in his experiments 0.5 milligramme.

‡ *Jour. Am. Chem. Soc.*, vol. xvi, p. 513.

The influence of silica being the special object of inquiry, other conditions, such as temperature, amount of silver and amount of test-lead, were kept as nearly constant as possible, to facilitate the comparison of results.

The table on page 557 shows the quantities of each ingredient of the charge, and the results obtained, other conditions of the experiment being stated in the following.

Remarks

All the assays were made in duplicate. In the column under "Silver," the amounts of silver actually weighed out are given, the following columns, for comparison only, give the average results.

Experiment No. 1.—In this case, the "low heat" was just sufficient to melt the lead; and the smaller percentage of silver recovered was due to the long period of scorification, which permitted a larger quantity of silver to enter the slag. The "high heat" was a white heat; and the loss here was probably due to volatilization.

Experiment No. 2.—As was to be expected, these assays show increasing loss of silver with increase of silica.

Experiment No. 3.—Here the addition of 6 grammes of SiO_2 increased the loss of silver.

Experiment No. 4.—In this case, the addition of SiO_2 increased the loss of silver, but variation of the ratio of SiO_2 to FeS_2 seems to have had no material effect in this respect.

Experiment No. 5.—The assays show that the addition of silica increases the loss of silver, and that this loss is diminished by a decrease in silica and an increase in zincblende. The well-known effect of zincblende, *per se*, in augmenting the loss of silver, was shown by additional assays (not reported in the table), in which still larger quantities (6, 8 and 10 grammes) of zincblende were present, with no silica. These assays yielded black, pasty slag, and very brittle (and in the last instance, with 10 grammes of zincblende, very small) buttons, which could not be cupelled.

Experiment No. 6.—In these assays, the amount of test-lead added was so proportioned to the lead in the galena as to make 50 grammes the total lead in the charge. With 4 and 10 grammes of galena the results were peculiar, the loss of silver

Table of Scorification-Assays.

Experiment No	Ore Grammes	Test-Lead Grammes	Silica Grammes	Silver Milli-grammes	Average Silver Re-covered Milli-grammes	Average Recovery Per cent
1 (Lead)	{	50 (Low heat)		{ 50 05 49 97	48 99	98 75
		50 (High heat)		{ 50 06 50 02	49 27	99 25
		50	2	{ 50 46 50 10	48 89	98 00
		50	4	{ 50 10 50 34	48 58	97 50
2 (Silica)	{	50	6	{ 50 14 50 24	48 23	96 85
		50	8	{ 49 99 50 08	46 26	93 25
		50	10	{ 50 10 50 11	44 84	90 25
		50	6	{ 50 30 50 10	46 18	93 15
3 (Stibnite)	{	1 5		{ 50 00 50 20	48 23	97 00
		1 5		{ 50 40 50 40	48 80	97 00
		1 5		{ 50 00 50 00	46 95	94 70
4 (Pyrite)	{	3	2	{ 50 00 50 20	47 20	94 80
		2		{ 50 10 49 94	47 75	96 20
		4		{ 50 08 50 42	47 65	95 60
5 (Blende)	{	1 5	6	{ 50 30 50 05	44 45	89 30
		3	2	{ 50 80 50 60	48 00	95 50
		2		{ 49 98 50 04	48 76	98 30
		4		{ 50 22 50 31	49 71	99 65
		6		{ 50 09 50 37	48 40	97 20
		8		{ 50 03 50 40	48 24	96 75
6 (Galena)	{	10		{ 50 20 50 03	49 12	98 80
		1 5	6	{ 50 30 50 30	47 65	95 40
		3	2	{ 50 20 50 90	49 80	99 30
		0 5	6	{ 50 40 50 40	46 40	92 10
		1	6	{ 50 50 50 30	47 35	94 70
		0 5	2	{ 50 10 49 90	49 35	99 45
7 (Sulphur)	{	1	2	{ 50 60 50 90	49 18	97 25

being smaller than with 2 grammes of galena, while the assays with 6 and 8 grammes of galena showed proportionately larger losses of silver. The addition of 6 grammes of silica, 1.5 grammes of galena being present, was followed by increased loss of silver, but the combination of 3 grammes of galena with 2 of silica resulted in the recovery of the largest percentage of silver (with one exception) in the whole galena-series.

Experiment No 7.—In these assays, the increase of sulphur in the charge from 0.5 to 1 gramme seems to have reduced the loss of silver (as the increase of sulphides seemed to do in preceding experiments). But the reduction of silica from 6 grammes to 2 increased, as in other cases, the proportion of silver recovered

Conclusions.

The preceding experiments indicate that the behavior of the metallic sulphides in scorification with silica and silver is not uniform, but varies with the nature of the ore. Evidently more extended investigation would be necessary to determine the cause and law of this variation.

These experiments, however, appear to warrant the following conclusions

1 That in assays of pure silver with lead, an increase in the amount of silica present increases the loss of silver in the slag. This fact was already well known

2 That in the presence of sulphides, an excess of silica increases the silver loss, but that this loss is apparently diminished when sulphides are present with a relatively smaller amount of silica

3 The experiments, though by no means conclusive, suggest that the same recovery of silver cannot be expected from different mixtures or ores of the same silver-value.

Dr. Koenig,* after observing that the student, operating with various type-mixtures (each containing exactly 300 oz. of silver per ton), "finds that the loss of silver is not at all the same, but that this loss can vary from 3 to 16 per cent with the best work possible," adds that an assay "made with clean sand, the 30 mg. of silver, wrapped in lead foil, being placed on the top of the charge, sand and test-lead, . . . gives the minimum loss."

* "Scorification and Cupellation Without Muffle," etc, *Trans*, xxviii, 284

The experiments above reported, and the results obtained by Messrs Furman and Dewey, seem to require a modification of this statement, since they indicate that the silver-loss would be dependent upon the amount of silica present, as well as upon the other ingredients of the charge.

My thanks are due to Dr E H Miller for friendly advice and assistance in the experiments above described.

Coal-Outcrops.

BY CHARLES CATLETT, STAUNTON, VA

(Canadian Meeting, August, 1900)

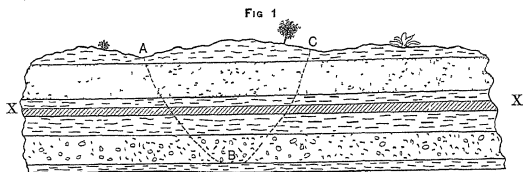
PROBABLY no one has had occasion to examine an undeveloped coal property without hearing some hopeful or interested party insist that the bed will improve when opened some distance under cover. When the bed is already in good condition, the opinion is usually advanced that the same character may be expected, at least to the bounds of the hopeful individual's holdings. My attention has been called in this way to the extent to which a bed is affected by its outcrop at the surface; and having had opportunity to examine a number of openings immediately at the surface, and also a short distance under cover, I submit some observations bearing on this question.

Whatever may have been the original variations, we may assume that coal-basins presented in comparatively modern times approximately parallel beds interstratified with fire-clay, slate, sandstone, etc., as represented by Fig. 1.

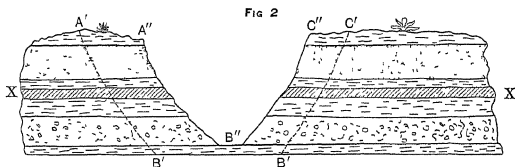
Under the effect of erosion, Fig 2 would be formed.

It is obvious that along the line A, B, C, in Fig. 1, the beds exist under conditions differing from those at A', B', C', or again at A'', B'', C'', in Fig 2, in their exposures to atmospheric agencies, pressure and erosion. The effect of the first is to decompose and soften many of the strata, of the second, when presented unequally, to cause the movement of such material as was at all plastic towards the point of least pressure; and of the third, to remove the strata in whole or in part. It

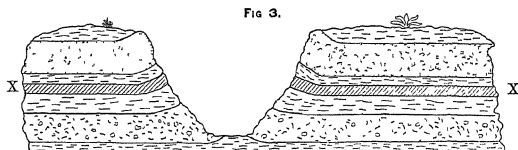
is obvious that the pressure is not as great at or near the outcrop as it is some distance under cover, and the tendency, therefore, would be to increase the thickness at the former point, and to give a result which might be represented by Fig. 3, in which each stratum is elevated by the sum of the thick-



Ideal Section of Coal-Bed, X-X, with Fire-Clay, Slate, Sandstone, etc., Above and Below.



First Result of Erosion upon Bed, X-X, Shown in Fig 1.



Second Result of Erosion, through Unequal Exposure and Pressure, Bending and Thickening the Outcrops

ening of all the strata beneath it. This result is exaggerated in the figure. It is usually not conspicuous, since the material thus forced to the surface is peculiarly subject to erosion and removal, so that the effect on the level of the various strata is small, and is often offset by local conditions. Yet it exists; and in places where the beds of coal are underlain by thick beds of

plastic fire-clay, they commonly show a dip from the outcrop, owing to the thickening of the fire-clay bed at that point. In illustration of the changes which may be expected to occur from the outcrop, or the first point where the full section of the coal is disclosed under an apparently undisturbed roof, to a point some distance from the outcrop, the following typical sections are furnished. They represent a wide territory, and come from Virginia, West Virginia, Kentucky and Alabama.

I

Outcrop Inches		50 ft from Outcrop Inches
31 coal,	.	33 { 24 coal
		2 hard coal
		7 coal
1 5 sandstone,		1 5 sandstone
14 coal,		14 5 coal
3 coal and fire-clay,	.	2 coal and fire-clay
9 coal,		10 coal
<hr/>		<hr/>
54 coal,		57 5 coal
4 5 partings,	.	3 5 partings
<hr/>		<hr/>
58 5	58 5	61 61

II.

Outcrop Inches		50 ft from Outcrop Inches
18 5 coal,	.	21 coal
parting,	.	parting
9 coal,	.	10 coal
1 sandstone (bituminous),		1 25 bitumin sandstone
14 5 coal,		15 coal
1 slaty material,		1 slaty coal
15 coal,		12 coal
<hr/>		<hr/>
57 coal,	.	58 coal
2 partings,		2 25 partings
<hr/>		<hr/>
59	59	60 25 60 25

III

Outcrop Inches		30 ft from Outcrop Inches
3 draw slate,		3 draw slate
19 5 coal,		19 5 coal
0 5 bituminous slate,		0 5 inferior coal
10 coal,		14 coal
1 sandstone,		1 5 sandstone
18 coal,		19 coal
1 fire-clay,		1 fire-clay
21 coal,		16 5 coal
<hr/>		<hr/>
68 5 coal,		69 coal
5 5 partings,		6 partings
<hr/>		<hr/>
74	74	75 75

IV

15 ft from Surface Inches		50 ft from Surface Inches
6 5 coal,		5 coal
0 25 parting,		1 bitumin slate
11 25 coal,	13 75 {	2 coal
1 sandstone,		1 75 hard coal
10 coal,		10 coal
1 slate,		1 sandstone
4 5 coal,		14 coal
2 25 fire-clay,		0 5 slate.
3 5 coal,		5 coal
6 fire-clay,		4 fire-clay
6 coal,		3 5 coal
		6 fire-clay
		6 coal
<hr/>		<hr/>
41 75 coal,		47.25 coal
10 5 partings,		12 5 partings
<hr/>		<hr/>
52 25 52 25		59 75 59 75

V

Surface—no roof exposed Inches		50 feet Inside Inches
16 coal,		20 coal
9 slate,		8.5 slate.
17 coal,		18 coal
<hr/>		<hr/>
33 coal,		38 coal.
9 slate,		8 5 slate
<hr/>		<hr/>
42 42		46 5 46 5

The average of 13 sections in the mine working this seam shows 35 5 inches coal and 15 3 inches slate

VI.

Outerop Inches		15 ft from Outerop Inches
14.5 coal, .		14 5 coal
0 5 slate,		2 slaty and bony coal.
5 5 coal,		
12 {		11 {
0 5 slate,		9 coal with bony streaks
5 5 coal, .		1.5 slate
0 5 slate,		15 5 coal
17. coal, .		<hr/>
<hr/>		41 coal
42 5 coal,		1 5 slate.
1 5 slate,		<hr/>
<hr/>		<hr/>
44 44		42 5 42.5

VII.

Outcrop Inches		30 ft from Outcrop Inches
6 5 coal,	. . .	11 coal
0 5 slate,	. . .	0 5 slate
11 coal,	. . .	6 coal
3 fire-clay,	. . .	3 hard fire-clay
2 coal,	. . .	1 coal
10 coal and slate,	. . .	7 coal and slate
14 coal,	. . .	12 5 coal
<hr/>		<hr/>
33 5 coal,	.	30 5 coal
13 5 partings,	. .	10 5 partings
47	47	41 41

VIII.

Outcrop Inches		66 ft from Outcrop Inches
24 coal,	. . . . .	21 5 coal
1 5 slate,	. . . . .	1 5 slate
1 5 coal,	. . . . .	0 75 coal
3 slaty coal,	. . . . .	0 75 slaty coal
27 coal,	. . . . .	29 coal
<hr/>		<hr/>
52 5 coal,	. . . . .	51 25 coal
4 5 partings,	. . . . .	2 25 partings.
57	57	53 5 53 5

IX.

Outcrop Inches		100 ft from Outcrop Inches
23 coal,	. . . . .	27 coal
.. parting,	. . . . .	0 75 parting
24 coal,	. . . . .	17. coal
1 slaty coal,	. . . . .	1 parting.
5 coal,	. . . . .	4 coal
<hr/>		<hr/>
52 coal,	. . . . .	48 coal
1 parting,	. . . . .	1 75 partings.
53.	53	49 75 49 75

X.

Outcrop Inches		250 ft from Outcrop Inches
13 coal,	. . . . .	13 coal
1 5 slate and sandstone,	. . . . .	1 5 slate and sandstone
5.5 {	2 coal, {
	1 slate, {
	2 5 coal, {
	14. slate and coal, {
	4 sandy slate, {
	24 coal, {
<hr/>		<hr/>
	41 5 coal, {
	20.5 partings, {
62.	62.	56 56

XI.

	Outcrop Inches				50 ft from Outcrop Inches
	13 coal,	.	.	.	11 coal
4	{ 1 slate,	.	.	.	3 cannel coal
	{ 3 coal,	.	.	.	
6.5	{ 1 5 slate,	.	.	.	
	{ 0 5 coal,	.	.	.	6 slate
	{ 4 5 slate,	.	.	.	
7	{ 2 5 coal,	.	.	.	6 coal.
	{ 4 5 coal and slate,	.	.	.	
	8 sandy slate,	.	.	.	11 5 sandy slate
	31 coal,	.	.	.	27 coal
	6 cannel coal,	.	.	.	8 cannel coal
	12 coal,	.	.	.	14 5 coal
	<hr/> 68 coal,	.	.	.	<hr/> 69 5 coal.
	19 5 partings,	.	.	.	17.5 partings
	<hr/> 87 5				<hr/> 87

XII.

	Outcrop Inches			15 ft from Outcrop Inches
	14 5 coal,	.	.	14 5 coal
	4 slate,	.	.	4 slate
	30 coal,	.	.	29 coal
	6. slate,	.	.	8 5 slate
	13 coal,	.	.	16 5 coal.
	0 75 coal and slate,	.	.	1 slate
28 5	{ 4 coal,	.	.	
	{ 0 5 slate,	.	.	21 coal
	{ 14 cannel coal,	.	.	
	{ 10 coal,	.	.	
	<hr/> 85 5 coal,	.	.	<hr/> 81 coal.
	11 25 partings,	.	.	13 5 partings.
	<hr/> 96.75			<hr/> 94 5

XIII.

Outcrop	50 ft from Outcrop	75 ft from Outcrop
43 5 clean coal	44 clean coal.	44 5 clean coal

XIV.

Outcrop.	50 ft from Outcrop	75 ft from Outcrop.
44 clean coal.	43 clean coal	42. clean coal

The average of the mine working this seam is between 44 inches and 46 inches clean coal.

In summary, the thickness of coal shows under cover an average increase of 6 per cent in 6 sections (omitting section X, in which the item of "slate and coal" at the outcrop vitiates the comparison), and a decrease of nearly 5 per cent. in 7; while the thickness of partings shows an average decrease of 30 per cent. in 6 sections (omitting XIII and XIV, which do not specify partings) and in 5 sections an increase of 27 per cent.

An examination of these sections will disclose a marked similarity between the seam at the surface and when opened a reasonable distance under a solid top, and this was borne out by numerous other examples which it is not necessary to give. Beds will vary from point to point, and will present often, without apparent reason, marked irregularities, but observation of these sections has convinced me that the changes due to the nearness of the surface *alone* can be recognized and allowed for, and that it is possible to form from the outcrop a very nearly accurate idea of what may be expected 50 or 60 or 75 feet under the top.

I briefly summarize the changes which may be expected. A very soft, sooty material, called by the miners "mother-coal," may pass, in that distance, into a coherent but friable material. It is usually exceedingly pure. Hard streaks in the coal are emphasized at the surface; and a material which is coal, but is obviously high in ash, may be found, owing to the increase of volatile and oily material, to become often of fair quality, on driving a short distance under cover, and be classed in a section at that point as pure coal. A slaty material which is very black and friable will, as a rule, pass into inferior coal, in the distance named, and, when in small quantities, would probably, in a section 50 feet from the outcrop, be described as bony coal. Hard, undecomposed gray slate, on a well-defined bed, may be expected to continue as such without, necessarily, an increase or decrease within the distance named. A plastic slate or a fire-clay, existing as a portion of the coal-bed, may usually be expected to thin very considerably within a short distance, as its section at the surface is, in nearly all cases, increased by the reduction of pressure at that point.

I would be glad to hear from other members of the Institute on this point, as a confirmation of these observations would make it very much easier and less expensive to prospect a coal-

property, and would often permit what, in my judgment, is far more desirable than to drive upon the seam under cover, namely, the making of a larger number of openings over a greater extent of outcrop.

**Notes on the Compressed-Air Haulage-Plant at No. 6
Colliery of the Susquehanna Coal Company,
Glen Lyon, Pennsylvania.**

BY J. H. BOWDEN, WILKES-BARRE, PA

(Canadian Meeting, August, 1900)

THE shaft-plant here described was put in operation in September, 1895, and the No. 6 slope-motor was started in May, 1896

The plant comprises.

One Norwalk three-stage compressor $12\frac{1}{2}$, $9\frac{1}{2}$ and 5 in diameters of air- and 20 in. diameter of steam-cylinder, all 24 in. stroke; capacity at 100 revolutions, 296 cu. ft. of free air per minute, compressed to 600 lbs. per sq. in. A main pipe, 5 in. diameter, 4380 ft. long, with five charging-stations in No. 6 Shaft, and a branch of 3 in. pipe, 3100 ft. long, with three charging stations, in No. 6 Slope. These pipes on each line charge a Porter compressed-air motor, with 7 by 14 in. cylinders, and four 24 in. drivers, weighing about eight tons, with a tank-capacity of 130 cu. ft. of air at 550 lbs. pressure in the main tank, reduced to 160 lbs. in the 8-in. auxiliary tank of 4.2 cu. ft. capacity, supplying the cylinders. The No. 6 shaft run averages 4000 ft. each way on grades of $\frac{1}{2}$ to $2\frac{3}{4}$ per cent., and averaging close to one per cent. in favor of the loaded cars. The No. 6 slope run averages 2100 ft. with nearly the same grades. The mine-cars weigh 2800 lbs. empty, and about 9800 lbs. loaded, and are hauled in trips of 12 to 20, averaging about 15 cars. The shaft-motor now hauls about 355, and the slope-motor 320 cars per day of 10 hours, replacing in the shaft 17 mules, and

in the slope 15 mules, or, in all, 32 mules, against 27 replaced in 1896.

The average daily car- and ton-mileage of each motor was as follows

No. 6 Shaft-motor,	<i>Cars Hauled.</i>			
		1896	1897	1898
		355	347.4	356
	<i>Tons Hauled One Mile.</i>			
		1896	1897	1898
	Empty, in, .	336	330	338
	Loaded, out,	1180	1155	1183
	Total, .	1516	1485	1521
	Net load,	844	825	845
	<i>Cars Hauled.</i>			
No 6 Slope-motor,		1896	1897	1898
		288	288 7	319 2
	<i>Tons Hauled One Mile.</i>			
		1896	1897	1898
	Empty, in, .	143	144	160
	Loaded, out,	501	504	560
	Total,	644	648	720
	Net load, . .	358	360	400
	Total for both motors, gross (including	1896	1897	1898
	empty cars returned), . . .	2160	2133	2241
Net load,		1202	1185	1245

The use of steam and air in operating the compressor and motor was found by test to be

Steam.

Indicated horse-power at 131 revolutions of compressor,	150 H P
Steam-consumption per H P per hour, from cards, . . .	34 lbs
“ per hour,	5,100 “
“ “ including condensation in line,	5,200 “
Boiler horse-power required,	174 B H P
Evaporation per lb of coal (cylinder-boilers),	5 lbs
Coal required per hour,	1,040 “
“ per day, 10 hours,	10,400 “ 4 65 tons
Cost of fuel and firing per day (10 hours) 4 65 tons, at 50c	\$2 32

Air

Compressor Capacity—The free air compressed per revolution of compressor is 2 96 cu ft. according to the calculation of the Norwalk Iron Works Co., no allowance being made for leakage.

The compressor works 12 hours per day, the motors 10 hours

Free air per minute at rated speed of 100 revolutions,	Cu ft
“ “ “ actual “ 131 “	296
“ per day 12 hours at rated speed of 100 revs ,	337.8
“ “ 12 “ actual “ 131 “	213,120
	279,216

Capacity of Air-Mains Used as Reservoirs—The capacity of the 5-in line, 4380 ft. long, is 608 cu ft ; and that of the 3-in. line, 3100 ft. long, is 159 cu ft., making the total for both lines 767 cu. ft.

At 600 lbs. pressure these lines hold 32,505 cu. ft. of free air. The capacity of the main and auxiliary tanks is 134.6 cu. ft. At 508 lbs pressure (at which they will equalize with the main, starting to charge at 600 lbs.), this is equivalent to 4845 cu ft. of free air

Leakage of Air-Mains—In standing 12 hours the pressure falls from 550 to 350 lbs., and of free air, 11,688 cu. ft., or 974 cu. ft. per hour, are lost. The proportion of this leakage to the total air compressed is 4.18 per cent.

Air Used by Motors.—According to a test made March 29, 1900, the amount of air used for the given amount of work was as follows :

	SHAFT-MOTOR		SLOPE MOTOR
	No 2 Plane	No 3 Plane	
Number of trips empty .	3	10	16
“ “ loaded .	3	10	15
Average No of cars per trip, empty,	15 33	12 7	11.4
“ “ “ loaded,	13	13	11 3
Average cu ft of free air per trip, empty	1724	5686	1230
Average cu. ft of free air per trip, loaded	1631	1898	599
Average cu ft of free air per round trip	3355	7584	1829

Summary of Day's Work in 1898.—At shaft No. 6, 356 cars were hauled per day; namely, from No. 2 plane, 6 trips of 15 cars each, using 20,130 cu. ft. of free air, and from No. 3 plane, 20 trips, averaging 13 3 cars each, using 151,680 cu. ft. of free air. The work at Slope No. 6 was 320 cars per day in 28 trips, averaging 11.4 cars each, and using 51,212 cu. ft. of free air, making a total for 676 cars of 223,022 cu. ft. of free air. The amount of free air apparently compressed for this work was 279,216 cu. ft., of which 83.4 per cent is accounted for, leaving 16.6 per cent. for leakage and slip in the compressor, leakage in air-lines, and changes in temperature.

Air Used per Ton-Mile.—The average volume of free air used per ton-mile is as follows

No. 6 shaft-motor, on gross tonnage,	.	Cu. ft.	113
“ “ “ net “	. .		203
No. 6 slope-motor, “ gross “	.		71
“ “ “ net “			128
Both motors, “ gross “	.		100
“ “ net “	.		180

The greater quantity of air used by the shaft- as compared with the slope-motor is due to the heavier curves and the switching required, especially at No. 2 plane, where a portion of the trip is frequently left

Cost of Plant—The cost of plant, not including steam-boilers, was as follows .

Compressor,	.	\$2,880 00
Extras for compressor-repairs,		75 75
Shaft-motor,	.	2,743 63
Slope-motor,	.	2,918 20
Extras for motor-repairs,	.	207 93
Air-connections, 5-in. line (6000 ft),		2,914 32
“ “ 3-in “ (4000 ft),		1,240 46
Steam-connections to compressor,		278 27
Material for compressor-foundations and house, and air-washing box,	.	295 27
Labor on compressor-house and foundations, and 5-in line, and installing shaft-motor,		1,183 01
Labor on 3-in line and installing slope-motor,	.	46 95
Foster equalizing-valves,		372 21
Total cost of plant,	.	\$15,156 00

Cost of Operation.—The operating expenses are shown in the following table:

	1897 (179 days worked)		1898 (160 days worked)	
	Per day	Per year	Per day	Per year
2 Motor-engineers, at \$2 10	\$4 20	\$751 80	\$4 20	\$672 00
2 Brakemen, at \$1 60. .	3 20	572.80	3.20	512 00
1 Engineer for compressor, at \$2 32	1 16	207 64	1 16	185 60
Oil for compressor	67	119 49	47	75 94
Oil for motors	.25	45 08	.25	40.94
Repairs for compressors (material)	10	18 76	48	76.08
“ “ (labor)	.06	10 38	09	15 22
Repairs for motors (material) .	16	28 78	51	81 08
“ “ (labor)	18	32.77	23	36 87
Steam for compressor (150 H P), fuel and firing	2 32	415 28	2 32	371 20
Total operating-expenses .	\$12.30	\$2202 78	\$12 91	\$2066 93

Fixed Charges.—The fixed charges are as follows

	1897 (179 days worked)		1898 (160 days worked)	
	Per day	Per year	Per day	Per year
Interest, repairs and depreciation of 174-H P boilers	\$1.46	\$261 00	\$1.63	\$261 00
Interest and depreciation of plant, 10 per cent on \$15,156 . . .	8 47	1515 60	9.47	1515.60
Total fixed charges .	\$9 93	\$1776 60	\$11 10	\$1776 60

Total Cost Including Fixed Charges.—The total actual cost in the two periods mentioned was, therefore, for the two motors (one-half to each), in 1897, per day, \$22.23, and for the whole period, \$3979 38; and in 1898, per day, \$24.01, and for the whole period, \$3843.83. Taking the figures of 1897 as a basis, and assuming 300 days of work in a year (with consequent saving in certain items of fixed charges, superintendence, etc.), it is estimated that the total cost would be \$18.22 per day, or \$5466.00 per year. A similar calculation, based upon the figures of 1898, gives \$18.83 per day, or \$5649.00 per year.

Cost Per Ton-Mile.—For the same two periods, the cost per ton-mile was as follows

	1897 (179 days)			1898 (160 days)		
	Daily Ton-Milage	Daily Cost	Cost per Ton-Mile	Daily Ton-Milage	Daily Cost	Per Ton-Mile
No 6 shaft-motor, gross	1485	\$11 12	0 75	1521	\$12 00	0 79
" " net	825	"	1 35	845	"	1 42
No 6 slope-motor, gross	648	"	1 72	720	"	1 67
" " net	360	"	3 09	400	"	3 00
Both motors, gross	2133	22 23	1 05	2241	24 01	1 07
" net	1185	"	1 89	1245	"	1 93

Cost of Mules Displaced by this Plant.—There were at No 6 shaft 17, and at No. 6 slope 15 mules, costing, on an average, \$126.64 each, or \$4052 for the two lots

Operating-Expense by Mules.—The expense of operating with mules would be as follows

	1897 (179 days)		1898 (160 days)	
	Per day	Per year	Per day	Per year
No 6 shaft				
Depreciation and interest on 17 mules, 25 per cent	\$3 01	\$538 22	\$3 36	\$538 22
Feeding, attendance, harness and repairs, \$141.40 per mule	13 43	2,403 80	15 02	2,403 80
6 drivers	9 40	1,682.60	9 40	1,504 00
6 couplers and spragmen	8 10	1,449 90	8 10	1,296 00
Total cost by mules	\$33.94	\$6,074 52	\$35 88	\$5,742 02
Cost by motor	11 12	1,989.69	12 00	1,921 77
Saving by compressed air	\$22 82	\$4,084 83	\$23 88	\$3,820 25
No 6 slope				
Depreciation and interest on 15 mules, 25 per cent	\$2 65	\$474 90	\$2 97	\$474 90
Feeding, attendance, harness and repairs, \$141 40 per mule	11 85	2,121 06	13 26	2,121 06
5 drivers	8 00	1,432 00	8 00	1,280 00
5 couplers and spragmen	6.85	1,226 15	6 85	1,096 00
Total cost by mules	\$29 35	\$5,254 11	\$31 08	\$4,971 96
Cost by motor	11 12	1,989 69	12 00	1,921.77
Saving by compressed air	\$18 23	\$3,264 42	\$19 08	\$3,050 19
Both No 6 shaft and No 6 slope				
Total cost by mules	\$63.29	\$11,328 63	\$66 96	\$10,713 98
Total cost by motors	22 23	3,979 38	24 01	3,843 53
Saving by compressed air	\$41 06	\$7,348 25	\$42 95	\$6,870 45
Total saving in two years,			\$14,218 70	
Total cost of plant,			15,156 00	

At the average rate of saving for 1897 and 1898, the entire cost of the plant would be saved in 361 working-days

The capacity of the shaft-motor is equal to fully double its present work, and the slope-motor is working at but about one-third of its capacity, while the compressor is doing all that it can, and a second one was ordered April 7, 1900. To operate the plant to the full capacity of both compressors, which, under

Cost Per Ton-Mile by Mules.

	1897 Tonnage			1898 Tonnage		
	Ton-Mile-age	Cost	Cost per Ton-Mile	Ton Mile-age	Cost.	Cost per Ton-Mile
			Cents.			Cents.
No. 6 shaft						
Gross	1485	\$33 94	2 29	1527	\$35.88	2 35
Net	825	"	4 11	845	"	4 25
No 6 slope.						
Gross	648	29 35	4 53	720	31 08	4 32
Net	360	"	8 15	400	"	7 77
Total, gross	2133	63 29	2 98	2241	66 96	2 98
net	1185	"	5 34	1245	"	5 38

the present conditions, would be about 4500 ton-miles gross or 2500 net per day for 300 days per year, would bring the cost of operation, including fixed charges, to about \$24.60 per day, or $\frac{547}{1000}$ of a cent per ton-mile gross and $\frac{984}{1000}$ of a cent per ton-mile net load. If all the work could be done by one motor under the conditions of No. 6 shaft, up to the capacity of the compressor, for 300 days per year, using only one crew, the cost of plant would approximate \$11,000, and the operating expenses, including fixed charges, would be \$10.86 per day for 2400 gross ton-miles, or $\frac{48}{100}$ of a cent per gross ton-mile and $\frac{81}{100}$ of a cent per net ton-mile

A further reduction of cost would result from re-heating the air at the motor, by passing it through water at the temperature of steam at 90 pounds pressure, by which method tests have shown a gain of about 50 per cent. in air-economy. It is probable that by this means one motor could be run to its full capacity (about 3000 gross ton-miles per day) with one compressor, at a total cost of \$10.80 per day, or $\frac{36}{100}$ of a cent per gross ton-mile, for 300 days' work per year, the saving of $\frac{9}{100}$

of a cent per gross ton-mile, or about 20 per cent over the last-mentioned conditions being due only to the greater air-economy; the fixed charges and labor-cost remaining practically the same.

For a detailed description of this plant, with illustrations, those who are specially interested are referred to the *Colliery Engineer and Metal Miner*, Scranton, Pa., for May, 1896, and to the Report for 1895 of the *Pennsylvania Bureau of Mines*, pp 104 to 110.

The Protection of Blast-Furnace Linings.

BY S S HARTRANFT, BUFFALO, N Y

(Canadian Meeting, August, 1900)

FURNACE-MEN of the present day agree very nearly as to the best cooling-devices for the protection of blast-furnace hearths and boshes, and the best location of the cooling-system in the brick-work for the maintenance of favorable furnace-lines throughout the blast. The replaceable bronze and copper plates are practically faultless; and there seems to be no reason why a furnace-hearth and bosh should not be held in good condition, by intelligent management and the use of replaceable plates, for a period several times the length of the average blast of to-day.

While furnace-men have taken these precautions to protect the hearth and bosh beyond the life of the lining, the portion of the lining above the mantle has been partly protected by some and wholly neglected by others. Some would not construct a furnace without mantle-plates, and others would not construct a furnace with them. In most cases, furnace-men have either trusted to Providence or to the bosh-plates for the continuance of favorable working-conditions above the mantle, and the prolongation of the life of the lining, consequently furnaces are constantly blown out for repairs to the lining, or for relining, when the hearth and bosh are in good enough condition to last through another blast.

The following extract from one of Mr. James Gayley's con-

tributions on American blast-furnace practice is of interest in this connection.

"One point particularly worthy of mention has been observed recently, viz That the removable bosh-plates of bronze or copper protect not only the bosh-wall, but also the whole of the upper lining, from the point where the stock strikes against the top-lining down to the mantle. The wear of the lining for double the production is only about half what it was when the bosh was protected differently. The result, as amply demonstrated by practice, is that the fuel-consumption does not increase with the length of the blast, as has been the usual experience, and it also follows that the production maintains its regularity."

In other words, according to Mr. Gayley's statement, the melting and wearing away of the lining to large diameter above the mantle can be retarded by the use of removable bosh-plates so as to increase the economical working-life of the furnace 100 per cent. The working-life of a furnace depends upon the ability of the lining, from the stock-line to the mantle, to withstand melting or wearing away, which causes extravagant fuel-consumption and irregular working. Consequently, it seems that furnace-men should endeavor to ascertain the lines necessary to insure good economical working-conditions, and to protect these lines as the hearth and bosh are protected, thereby making the life of the lining from the mantle to the top equal to the life of the hearth and bosh.

My predecessor in charge of the Buffalo furnace informs me that, in a former blast, the furnace had the following dimensions diameter of hearth, 11 ft; diameter of bosh, 18 ft., angle of bosh, 75° ; and that it was provided with replaceable copper plates up to the mantle, and three rows of double-pipe cast-iron plates of the ordinary type above the mantle. The inner $1\frac{1}{4}$ in. pipe was $2\frac{1}{2}$ in. from the inner edge of the plate and the outer $1\frac{1}{4}$ in. pipe was 6 in. from the inner pipe, and parallel to it, both running lengthwise through the plate, which was 8 ft. in length. The first row of these plates was placed 5 in. above the mantle, with the front edge of each plate $4\frac{1}{2}$ in. from the inside line of the brick-work; the second row was $2\frac{1}{2}$ ft. above the first, with the front edge of each plate 9 in. from the inside line of the brick-work; and

the third row was $2\frac{1}{2}$ ft above the second, with the front edge of each plate $4\frac{1}{2}$ in from the inside line of the brick-work.

After blowing-in, the furnace worked very well for the greater part of the first year, when it began hanging and slipping, which gradually became so pronounced as to interfere materially with the grade of the iron. About the end of the first year, the water-circulation was lost on the inner pipes of the three rows of plates above described; after which there was no more hanging and slipping, while the grade of the iron improved and the output increased. In about a year and a half from the time the inner rows of pipes were lost, the outer rows were lost also, and, there being no water-protection left, the furnace soon enlarged at this point to such an unfavorable diameter and shape that it became necessary to blow out at the end of the third year.

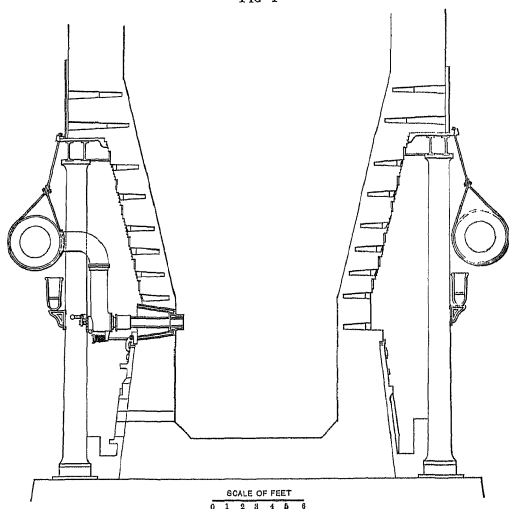
On several occasions, I have cut the water off from the inside pipes in three or four of the upper rows of bosh-plates, usually after the furnaces had been in blast a year or more, and the inner pipes had been lost in a few of these plates. A quick and favorable response was invariably noticed, in the way of improvement in grade and increase in output.

The wearing away of the brick-work above the upper row of plates, while the latter preserve nearly the original interior line, causes at that level a sudden recession of the wall, leaving a sort of lodge, which interferes with the regular descent of the stock, in proportion to the depth of the recess thus formed. This effect (when the plates are placed, as is customary, with their front edges a few inches from the original inside of the brick-work) is generally noticeable about the middle of the blast. I think that the wearing away of the lining could be sufficiently retarded to insure the retention of favorable lines, through the period of an average blast, by six rows of plates above the mantle, placed $2\frac{1}{2}$ ft. apart, with their front edges at least 9 in. from the inside line of the brick-work.

It has been the experience of some furnace-men, who place plates above the mantle and extend them through the lining until the front edge of each plate is within a few inches of the inside of the brick-work, that the furnace does better work when the first row of pipes in the plates burn off, and the

diameter of the furnace enlarges until the second or rear row of pipes prevent further enlargement in diameter. When the last row of pipes in these plates burn off, and all protection is lost, a further enlargement in diameter causes extravagant fuel-consumption and irregular working, to such an extent that it becomes necessary to blow out the furnace and put in a new lining. It seems, therefore, from experience with these plates, that in

FIG 1



Section of Blast-Furnace, with Replaceable Copper Plates up to the Mantle, and Double-Pipe Iron Plates Above.

a furnace of modern lines, to secure the protection of plates and the retention of favorable lines for a period more nearly approaching the life of the hearth and bosh, the plates should be placed with the front edge from 9 to 12 in. from the inside of the brick-work. This will permit an enlargement of diameter of from 18 to 24 in., without destruction of the plates; and if the furnace can be held by the plates after this

Fig. 1, taken from a recent drawing made by an eminent blast-furnace engineer, shows the hearth and bosh of an 18- by 80-ft. furnace with an 11-ft hearth and 75° angle of bosh, fitted with replaceable copper plates up to the mantle, and double-pipe iron plates above the mantle.

I have had an opportunity recently to observe the result of fitting up a furnace with rows of solid cast-iron plates at the stock-line, and I am much pleased to find how well these plates, with an inner edge 5 in. wide, placed in rows one foot apart, have worn, and have protected the lining at this point. I would not be surprised to see, before long, furnace-stacks plated from the mantle to a point above the stock-line with water-plates and solid plates. The only question difficult to decide will probably be the point in the ascent at which the water-plates should stop and the solid plates begin.

Considering the great progress of furnace-practice in recent years, especially in the matter of the protection given to furnace-hearths and boshes, it seems that the linings from the mantle up have not had a corresponding share of protection, and that in the near future this portion of the stack will be equally protected with the hearth and bosh from the effects of heat and abrasion, so that a great increase in the length of blasts, or the amount of iron made on one lining, may be expected.

Metasomatic Processes in Fissure-Veins.*

BY WALDEMAR LINDGREN, WASHINGTON, D. C.

(Washington Meeting, February, 1900)

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* Presented by permission of the Director of the U. S. Geological Survey.

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PART I.

GENERAL FEATURES

Purpose and Extent of Inquiry.

A study of the changes in rocks contiguous to ore-bearing fissures is essential to a thorough understanding of the genesis of such deposits. Nevertheless, comparatively little work has been done in this direction, though many mining geologists (for instance, v. Groddeck) long ago emphatically declared the necessity of such investigations. Ores and structure have been dealt with in detail; but the important changes which adjacent rocks of known composition have suffered are too often briefly dismissed, or even incorrectly indicated. It is the purpose of this review to collect the scattered data relating to the alteration of rocks near or between fissures, to indicate the principal active processes; to classify the veins, if possible, according to the different phases of alteration accompanying them; and, finally, to draw some conclusions from the facts thus grouped. This first attempt to systematize the metasomatic data of fissure-veins is by no means complete: only such parts of the American and foreign literature are represented as were deemed to be of vital importance. The discussion principally involves the changes which the country-rock has undergone, whether they have resulted in the formation of *ores* or not, and, in the second place, some space is devoted to such alterations as fissure-veins already formed sometimes suffer through certain secondary agencies. I have excluded, however, all references to weathering, or to the decomposition of vein-materials near the surface by waters containing free oxygen. It is often difficult to draw the line between normal fissure-veins and deposits not

to be regarded as such, strictly speaking, but clearly due to the same genetic causes; and some of the latter class have been included in this discussion.

Definitions.

Fissure-Veins —For the present discussion, a fissure-vein may be regarded as a mineral mass, tabular in form, as a whole, though frequently irregular in detail, occupying or accompanying a fracture or set of fractures in the enclosing rock; this mineral mass has been formed later than the country-rock and the fracture, either through the filling of open spaces along the latter, or through chemical alteration of the adjoining rock. Such alteration does not ordinarily extend far from the fissure. Only in regions where the vein-forming agencies have acted with unusual intensity, a partial alteration may extend over larger areas. These zones of alteration being genetically connected with the veins proper, must necessarily also be considered in this discussion.

Metamorphism —This term, meaning strictly a change of form, was proposed by Lyell in 1831, and has since been employed in a wider sense, so as to cover any change in the composition or structure of a rock, through whatever agency, and whether with or without gain or loss of substance.

Metasomatism.—This name, meaning a “change of body,” is given to that variety of metamorphism which involves a change in the chemical composition of rocks, by the addition or subtraction of substance*. The terms “replacement,” “substitution,” “alteration,” etc., have been employed in discussions of metasomatism with different shades of meaning. A review of the classification of pseudomorphs, which form the origin of our knowledge of metasomatism, will throw light upon the nomenclature of the subject.

The occurrence of organic remains, consisting of material of which they were certainly not originally composed, called attention to the remarkable transformations now known as metasomatic replacements. As instances, we may recall corals changed into quartz, belemnites converted into barite, and shells of bivalves or gasteropods transformed into pyrite, chalcocite,

Dana (*Man of Geol*, 4th ed, p 314) proposes for the same process the term “metachemic,” but this has not found general acceptance

sphalerite or specularite. To the same order of phenomena belongs the silicified wood, in which the organic substance has been removed and replaced with silica so delicately as to preserve in minute detail the original organic structure. This replacement is probably due to the precipitation of silica from solution by the acids generated in the decay of organic matter. More rarely, wood and plant-remains may be replaced by pyrite, chalcocite, galenite, cinnabar, barite, limonite, malachite, etc.

But it is the study of pseudomorphs, showing one mineral appearing in the crystal-form of another, that has led to a more detailed knowledge of the chemical laws which govern these remarkable changes. Here was conclusive proof that one mineral, definitely crystallized, had changed into another, sometimes totally different, substance. Naumann says of pseudomorphs

“Their importance cannot be overestimated, because they enable us to study successfully the laws of the processes which are constantly acting in the rocks and constantly changing them, for the pseudomorphs represent only one special case of the grand process of chemical alteration going on in the mineral kingdom, namely, that in which the form remained in spite of the change. From these we may draw conclusions as to the chemical processes going on in rocks which may change each grain to another mineral.”

Blum, who made the first extensive examination of pseudomorphs, divided them into (1) those produced by partial change in the composition of the original mineral (one or more elements being removed, added or introduced by substitution), and (2) those produced by a complete replacement of the original mineral with another. (This class includes both those produced by chemical replacement and by previous solution and subsequent filling.)

Naumann, in his well-known text-book of Mineralogy, divided the pseudomorphs into (1) hypostatic pseudomorphs, formed by the mechanical deposition of substance outwards or inwards from the limiting planes, and again subdivided into pseudomorphs by covering, and pseudomorphs by filling, (2) metasomatic pseudomorphs, formed by the alteration of the substance by means of its molecular replacement with another mineral while the form has been preserved. The metasomatic

* *Mineralogie*, Naumann-Zirkel, 10th ed., Leipzig, p. 112

pseudomorphs are also designated as "alteration" (*Umwandlung*) pseudomorphs. This, it will be noted, is the first introduction of the word *metasomatic* in technical literature. In nearly all cases, the metasomatic pseudomorphs involve chemical action.

Naumann further divides the metasomatic pseudomorphs into three classes, in which, respectively, (*a*) the original and the secondary substance are identical in chemical constituents ("paramorphic" pseudomorphs), or (*b*) chemical alteration has left one or more elements of the original in the secondary substance; or (*c*) the replacement of constituents has been complete, as in the substitution of galenite for calcite, or pyrite for quartz, but the process has been, nevertheless, a chemical one, since the removal and deposition have proceeded simultaneously, molecule for molecule. The second of these classes is again subdivided, according as the change involved simply the loss of original components (as in the formation of argentite from pyrargyrite), or the addition of components (*e.g.*, angle-site from galenite), or the exchange of components (*e.g.*, sericite from oligoclase)

The conceptions of Blum were introduced into English technical literature by James D. Dana,* who divided pseudomorphs into those formed (1) by infiltration (mechanical deposition in a mould already formed); (2) by incrustation (mechanical covering of crystals), (3) by replacement, one mineral gradually replacing another, and assuming at the same time its form, without any interchange of elements (the process being in a certain sense chemical, and wholly different from simple deposition), (4) by alteration, some of the elements being removed or exchanged, or new ones being added, and (5) by allomorphism, without chemical alteration, the body changing to one of the same composition but of different crystallographic system (the paramorphic pseudomorphs of Naumann).

Somewhat extreme views, differing from the above, were advanced by T. Sterry Hunt,† who classed pseudomorphs as: (1) those produced by chemical alteration, meaning by this a partial exchange of constituents (*e.g.*, limonite after siderite); and (2) those produced by substitution or replacement (those

* *American Journal of Science*, vol 48, 1845, p 81.

† *Systematic Mineralogy*, New York, 1892, p. 111

terms being evidently regarded as equivalent). The latter he believed to be produced by deposition in spaces left by the removal of some other matter. The form of the original substance is assumed by the material which displaces, or is substituted for it, *e.g.*, quartz after calcite, barite, etc. While thus admitting partial alterations, Hunt makes a special case of a complete replacement, refusing to consider it as a chemical process, and regarding it always as an instance of separate dissolving and refilling. To the theory of metasomatism, which maintains that all the chemical elements in a crystal may be removed, and by molecular processes replaced with foreign substances, Sterry Hunt was strongly opposed.

Pseudomorphs of the second group proposed by him are, as is well known, of frequent occurrence, and correspond to Naumann's hypostatic division or pseudomorphs formed by mechanical deposition. Spaces of dissolution, subsequently filled, are also common enough in rocks, and may usually be readily identified as such under the microscope. But that molecular replacement, as defined by Naumann and Dana, also exists, and, moreover, is of the highest importance, seems at present beyond doubt.

As the essential process of metasomatism applies as well to an irregular grain as to a perfectly developed crystal, we are justified in extending the conception to aggregates of grains of one or several minerals, in other words, to rocks and mineral aggregates in general. In this sense C. R. Van Hise* has defined metasomatism as "the process of metamorphism by which original minerals are partly or wholly altered into other minerals, or are replaced by other minerals, or are recrystallized without chemical changes, or one or all of these together." S. F. Emmons has defined metasomatism as follows †

"By metasomatic exchange is meant an interchange of substance without necessarily involving, as does pseudomorphism, the preservation of the original form of the substance replaced, or even of its original volume."

A second definition, based on the consideration that practically simultaneous solution and deposition could certainly be proved

* "Principles of Pre-Cambrian Geology," 16th Ann. Rept., *U. S. Geol. Surv.*, part 1, p. 689.

† *U. S. Geol. Surv.*, Monogr. XII, p. 565.

for many cases, where the exact proof of chemical-molecular replacement could not be furnished, is given by Mr. Emmons as follows.*

“ By metasomatic interchange I understand an interchange of substances, but not necessarily molecule by molecule, in such a manner as to preserve the original structure, form or volume of the substance replaced ”

The fundamental difficulty is that the final result does not always indicate the particular pseudomorphic process which has preceded. Mechanical deposition, for instance, may follow so closely after dissolution, that the two processes really appear as one. It may also be said that molecular replacement is difficult to prove, as molecular processes cannot be followed with the microscope, and this is, in a sense, true. We may assert, however, that, with the highest magnifying powers, we are able to follow the transformation of quartz, for instance, into sericite, or into calcite, or into siderite, without finding the slightest indication of an intermediate stage of open space. The fiber and blades of sericite project into the quartz without the slightest break in the contact; the rhombohedrons of siderite develop in quartzite, their crystal faces cutting across the grains without any interstices. Perfect tourmaline prisms develop in feldspar grains, and sharp cubes of pyrite in primary granitic quartz.

In cases of complete molecular replacement, such as galena after calcite, the replacing mineral was probably present in the solution, partly dissociated or ionized. The solution of a certain quantity of the original mineral caused the separation of a corresponding quantity of the ions of the replacing substance, according to physico-chemical laws. If carried out on these lines, the process is necessarily molecular and chemical. Where there were two solutions—one dissolving, the other depositing—and where a certain time intervened, the process is a mechanical one and should not, I think, be considered metasomatic. In many cases the distinction may be very difficult to draw.

In conclusion, metasomatism might be defined as the process by which a mineral has suffered, through chemical processes, a partial or complete change in its chemical constitution. Rocks or aggregates of minerals are “ metasomatic,” if any or

* “ The Genesis of Certain Ore-Deposits,” *Trans*, xv, 128, 1886

all of the constituent minerals have undergone such changes. This definition excludes the process of paramorphism which, as already emphasized by Naumann, is exceedingly rare.

In the use of the term *alteration* it would perhaps be best to follow Dana and let it mean a partial change of substance in a mineral or rock. *Decomposition*, it would seem advisable to restrict to the cases in which a mineral or rock is dissolved into its component parts, and a principal use for it would be found in the processes of weathering.

As has been shown, the words *replacement* and *substitution* have been used in very different ways. The majority of recent authors use them both as equivalent to metasomatism. Dana, however, applies *replacement* to a complete exchange of substance, reserving *alteration* for a partial loss, gain or interchange of elements; while Sterry Hunt gives the name of *replacement* or *substitution* to mechanical dissolution and the filling of the resultant cavities.

The chemist has, however, a distinct definition of *substitution* as "the replacing of one or more elements or radicals in a compound by other elements or compounds;" and it would probably be best to adhere to this, and discard *substitution* as a synonym for metasomatism or alteration.

Replacement is, in its general meaning, nearly identical with *substitution*, although it has no such distinct chemical use. It would seem advisable to regard it as a synonym of metasomatism, distinguishing, for the sake of convenience, between partial and complete replacement. This is contrary to Dana's distinction, but the word has been used so generally during late years in this wider sense that it seems best to retain this meaning for it.

Impregnation.—This term has been applied in so many different ways—to primary disseminations, to minerals formed by replacement; and to the filling of cavities or interstitial spaces in rocks—that it might well be rejected altogether as a genetic term, and used only in a structural sense, as descriptive of finely divided material disseminated in a differing mineral or rock-mass.

Cementation.—This term, proposed by Prof C. R. Van Hise,*

* "Pre-Cambrian Geology" 16th Ann. Report U. S. G. S., part i, p. 684

is convenient and expressive for the purpose of indicating filling of interstices in porous or shattered rocks. Cementation assumes importance in proportion to the porosity of the rock, which, in sandstones and tuffs, may reach 10 or 20 per cent. In most intrusive igneous rocks the porosity is so small as to be a negligible quantity.

Weathering.—Under this name are included the changes of rocks near the surface in cohesion and composition, due to the decomposing and oxidizing action of percolating waters above the permanent water-level. The tendency of weathering is to destroy the rock as a geological unit. The final results of metasomatic action are a few resistant minerals, such as quartz, kaolin and limonite. The formation of serpentine, chlorite, epidote and (ordinarily) pyrite is not weathering, but is due to more deeply seated causes. The German usage of *Verwitterung*, to cover all secondary changes, due to weathering, thermal and other causes, seems highly objectionable, and especially apt to lead to many misconceptions.

In view of the difference of usage as to many of the above definitions, it is to be hoped that writers upon this subject will take pains to indicate the sense in which the various terms are employed by them.

*Metasomatism in Connection with Mineral Deposits, Especially
Fissure-Veins*

It was not long before the principles of metasomatic action, learned by the study of pseudomorphs, were applied to larger masses of rocks. This led, perhaps inevitably, to exaggerated notions, such as that of the formation of true granites from sediments and limestone,* etc.; and this undue extension was followed by a reaction, exemplified in Sterry Hunt's writings.

The observation that ores may be found, not only in the clearly defined vein-filling, but also in the rock adjacent to the fissure, is contemporaneous with almost the earliest scientific records of mining. Sandberger† mentions the occurrence of masses of native silver, found in 1786 in the altered granite of certain Schwarzwald veins, which greatly astonished the old miners. Vogelgesang,‡ in Cotta's "Gangstudien," describes

G Bischof, *Chem. Geol.*, Bonn, 1866, vol. iii, p. 34.

† *Erzgänge*, part ii, p. 418.

‡ Vol. ii, Freiberg, 1854, p. 78.

the dissemination of argentite, native silver, and various sulphides, in the gneiss adjoining certain veins near Freiberg.

But whether or not it contains ore, the rock adjoining a vein is very commonly softened, bleached and altered for some distance away from the fissure. This phenomenon has been explained in two radically different ways

1 Bischof says †

“As we find ores in veins, proportionate in quantity to the alteration of the country rock, what other relation can be thought to exist between the two facts than that the abundance of the ore is a result of this alteration?”

Sandberger says ‡

“The extent of the alteration on both sides of the vein corresponds with the area from which the products of leaching have been carried to the vein”

2. The opponents of these views say that the narrow zone of alteration, intense next to the fissure and gradually fading away within a short distance from it, most clearly indicates an agency within the fissure, acting with gradually diminishing energy on the adjoining strip of rock. They also point out that Bischof's premise, *viz.*, the coincidence of richness of vein and extent of the altered zone, is not true as a universal proposition. And they show, further, that as the whole altered zone has, in many cases, received an addition of the same metals as are contained in the vein which may more than counterbalance its losses of other constituents, Sandberger's conclusion can certainly not have a general application, and finally, that, in those veins which have no gangue, but in which the ore has accumulated in the rock during the alteration, the incorrectness of that conclusion is particularly apparent.

Veins carrying cassiterite early attracted attention, as being almost always accompanied by ore impregnating the surrounding country-rock. The metasomatic character of the process was first shown by Daubrée‡ and later by Cotta,§ both of whom, in support of their views, call attention to the well-known occurrence of cassiterite as a pseudomorph after feldspar. Both explain the alteration as due to gradual replace-

* *Chem. Geologie*, Bonn, 1866, vol. III, p. 666

† *Ergänze*, vol. 1, p. 149

‡ *Ann. d. Mines*, 1841, xx, pp. 65, 72, 83

§ *Die Lelwe von den Erzlagertstätten*, Freiberg, 1859

ment by the agency of thermal waters. This explanation was substantiated by more recent and detailed investigations; for instance, by Richard Pearce (1864) and LeNeve Foster (1877) in regard to Cornwall, and by A. W. Stelzner (1864) for Geyer, Saxony.

The views of Cotta concerning the alteration of the wall-rocks or veins are well expressed in the following paragraph.¹

"When lodes are accompanied by ore-impregnations, it is to be assumed that generally the solutions from which the materials of the lode were precipitated—they may have been aqueous, igneous-fluid, or gaseous—also penetrated the wall-rock and there caused certain deposits in fine clefts or in the rock itself. In the last case, crystals have made room for themselves by their power of crystallization, or an ore took the place of the mineral dissolved, for example, tin-ore, that of feldspar."

This quotation shows plainly the clear conception which Cotta had of the alteration of rocks, as due, not only to filling of pores and cracks, but also to processes of replacement active within the rocks.

Although Cotta made no special division of replacement-veins, he was well aware of their occurrence and perfectly able to distinguish them from filled spaces. Describing the gold-veins of Tauern (Austria),[†] he says that they have not the character of clearly opened and filled fractures, but consist of several parallel tight fissures, between which lies more or less impregnated and altered country-rock. The gold penetrates into the country-rock from the fissure, and the tenor decreases gradually with increasing distance.

In 1873 Posepny published his famous examinations of the Raibl deposits.[‡] These are not connected with fissures, but deserve mention, since entirely similar processes are active in fissure-veins. Posepny found that carbonate of zinc had replaced carbonate of lime "by metamorphic processes."

Von Groddeck, in his well known text-book (1879), includes "metamorphic" deposits in his system, but limits them to replacements of limestone by zinc-, iron- and manganese-minerals. At about the same time, Stelzner, in his lectures, introduced a corresponding division of "metasomatic deposits,"

* *A Treatise on Ore-Deposits* (Prime's Translation.) New York, 1870, p. 90.

† *Die Lehre von den Erzlagernstätten*, Freiberg, 1859, part II, p. 318.

‡ *Jahrbuch d. k. k. Geol. Reichsanstalt*, xxiii, 1873, p. 317.

though they were still limited to a relatively small number of the irregular masses in limestone

Raphael Pumpelly was, I believe, the first who applied the principles of metasomatism to ore-deposits in this country, in describing the copper-deposits of Michigan (in part fissure-veins) in vol. 1. of the Geological Survey of Michigan (1873), and in his noted paper on the "Metasomatic Development of the Copper-Bearing Rocks of Lake Superior"* The copper, to a great extent, replaces other minerals.

In 1879 J. A. Church published a volume on the Comstock mines,† in which he maintained the origin of the quartz by replacement acting from a number of narrow fissures

In 1882 S. F. Emmons first published the results of his examinations of the Leadville silver-lead deposits, in which it was shown that these were entirely formed by metasomatic replacement of the limestone by galena and other minerals. A little later, J. S. Curtis published his first results in regard to the silver-lead deposits of Eureka, Nevada, in which he arrived at substantially the same results as Mr. Emmons. Though these deposits, as well as those of Leadville, are not to be regarded as fissure-veins, it was evident that the same process might be considered as active along fissures, provided the waters circulating in them had the composition attributed to those of Leadville and Eureka. The results obtained were certainly of the greatest interest to students of fissure-veins, and threw a new light on many obscure facts. During the following years, Mr. Emmons, who had visited a great number of mining regions in the West containing fissure-veins, published several papers,‡ in which he maintained that, for a great number of the veins formerly considered as containing ore deposited in open spaces, another and much more plausible explanation could be advanced, namely, that, in many cases, the fissures had not been opened to any noteworthy extent, but only so much as to admit the passage of the mineral-bearing waters. The latter had attacked the rock on either side of the fissure, and, by a process of metasomatic replacement, had deposited ores in the place of

* *Proc. Am. Acad. Arts and Sci.*, vol. xiii (new series, vol. v), 1878, pp. 253-309

† *The Comstock Lode*. New York, 1879

‡ "The Genesis of Certain Ore-Deposits," *Trans.*, xv, 125, 1886, "Structural Relations of Ore-Deposits," *Trans.*, xvi, 804, 1887.

the simultaneously dissolved rock-constituents. Applying this process to composite veins, consisting of a number of narrow fissures, and considering that gradual replacement had taken place, extending into the rock on each side of each smaller fissure, Mr. Emmons succeeded in showing how, under certain circumstances, a banded structure such as had ordinarily been attributed to the filling of open spaces could to some extent result from the process of replacement.

During the following years the theory of the formation of fissure-veins by replacement rapidly gained ground; and for some time it seemed as if the old view of deposition in open spaces were doomed to complete extinction. Carried away with the importance and interest of the metasomatic theory, many geologists and mining engineers extended its teachings beyond proper bounds, and were prone to speak of any fissure-vein as unquestionably a product of replacement. Attempts were made to show that open fissures could not exist unsupported, at any rate below the most superficial depths, and facts and proofs were too often neglected for bare assertions that metasomatic replacement had taken place. Posepny, in the discussion of his paper,* protested against this unwarranted extension of a most excellent and well-founded theory, and stated with some force that the experience and observations of a hundred years were not to be thrown away without very careful scrutiny. The pendulum had now swung to its extreme position; and it was not unnatural that a reaction should follow. It gradually became clear on the one hand that open spaces can and do exist down to a depth of many thousand feet,† and that these open cavities may be filled by the action of mineral-bearing water. On the other hand, it is evident that there is ample room for processes of replacement in fissure-veins, which may either affect the surrounding country-rock without producing notable amounts of ore, or, on the other hand, may attack it in such a way as to convert it wholly or partially into valuable minerals.

Some kind of metasomatic action is usually noticeable in the rock adjoining the fissure. But it is not to be denied that in many cases this alteration is very slight, and in a few veins it may be entirely absent.

* *Trans*, xxiv., p. 968

† Van Hise and Hoskins In "Principles of Pre-Cambrian Geology," 16th *Ann. Rept. U. S. Geol. Surv.*, part i.

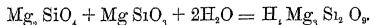
Calculation of Analyses.

In order to trace the metasomatic changes by which one mineral has resulted from another, it is necessary to know the composition of each, and the change in volume during the alteration. Without the latter the problem is capable of many solutions, any one of which may be possible, though not true. Only when some definite data, such as the constancy of one constituent, are available, can the changes be determined without reference to relative volumes. For instance, the percentage-composition and specific gravity of argentite and pyrrargyrite are as follows

	S Per cent	Ag Per cent	Sb Per cent	Sp Gr
Argentite (Ag_2S),	13.0	87.0		7.0
Pyrrargyrite (Ag_3SbS_4),	18.0	60.0	22	5.8

Pyrrargyrite may be altered into argentite, but analyses alone give no complete clue to the character of the alteration. Supposing, however, that we have found that 1000 cub centim of pyrrargyrite becomes 570 of argentite, then we may calculate that about 9 kilos of sulphur and 22 of antimony have been removed from 100 kilos of pyrrargyrite during the process, while the silver has remained constant. Supposing, again, that we have found pyrrargyrite altered into argentite without change of volume, then from the original 100 kilos, 2.24 of sulphur and 22 of antimony have been lost, and 44.8 of silver added.

To exemplify further the many ways in which even simple metasomatic problems can be solved, we may take the well-known change of olivine to serpentine, consisting, as ordinarily considered, in a simple hydration of the original mineral. And, in order to simplify the matter still further, we may substitute for olivine the pure magnesium orthosilicate, occurring as a mineral under the name of forsterite, and assume the resulting serpentine to contain no iron. The formulas show that serpentine cannot be derived from olivine or forsterite by means of a simple addition of water. It may, however, be derived from enstatite (which is a magnesium metasilicate) and forsterite, as follows:

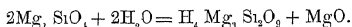


Translated into kilograms, this means that 50.8 kilos of forsterite + 36.2 of enstatite + 18 of water is equal to 100 kilos of

serpentine. This again translated into volumes by aid of the specific gravities, means that 15.8 cb. cm. forsterite + 11.7 cb. cm. enstatite + 13 cb. cm. water is equal to 40 cb. cm. serpentine, or that 27.5 cb. cm. anhydrous silicates are needed to produce 40 cb. cm. serpentine. In other words, the increase of volume during the process of serpentinization amounts to nearly one-half,—the specific gravity of forsterite being 3.24, that of enstatite, 3.1; and that of serpentine, 2.5.

Serpentine may also be obtained by adding silica and water to forsterite. Thus, $3\text{Mg, SiO}_4 + 4\text{H}_2\text{O} + \text{SiO}_2 = 2\text{H}_4\text{Mg, Si}_2\text{O}_9$. Calculating in the same manner as above, we find that 131 cb. cm. of forsterite results in 221 of serpentine, which represents an increase in volume of somewhat more than two-thirds.

Still another way of derivation is by subtracting MgO and adding water, as shown by the following formula



This again is equivalent to the formation of 110.4 cb. cm. of serpentine from 86.3 of forsterite, or an increase of volume of only a little more than one-fourth.

Many other formulas could be put forward, which would explain the formation of serpentine, each showing a difference in the relation of volume of the secondary mineral to that of the fresh. Even in this simple case it might be, in any given problem occurring in nature, extremely difficult to decide with confidence which particular formula should be applied. The problem only becomes definite when we positively know the relation of volume of original substance to that of secondary substance. It is perhaps superfluous to add that the mere knowledge of specific gravities does not give this relation of volumes.

When we have to consider metasomatic processes affecting rock-masses, aggregates of from two to six or more minerals, the complexity of the problem becomes immensely greater; for each of these constituent minerals may have suffered different metasomatic changes. Some may have remained unaltered, while others have been completely replaced; and others, again, may have lost, or gained, or exchanged one or more elements. To calculate the sum total of these changes is often an extremely puzzling task.

The mineral composition of the altered, as well as the fresh, rock may be accurately calculated by methods known to petrography, if its analysis, as well as those of the constituent minerals, be available. Even where the latter are only approximately known, a fairly accurate calculation may be made. Thus, for instance, from an analysis of an altered granite containing pyrite, calcite, magnesite, siderite, sericite and quartz, the percentages of these minerals may be obtained with fair accuracy.

The chemical changes suffered during any alteration of a rock may be considered by unit-weight of original substance or by unit-volume of the same. The results will be identical if both rocks are non-porous, or if both have the same porosity. If the actual additions and subtractions should happen to balance, then the percentage-analyses offer, by comparison, direct evidence as to the quantitative alteration. If, besides, during the alteration, the porosity of the two rocks remain the same, then the changes measured by unit-weight will be identical with those measured by unit-volume. This exact balancing of gains and losses, however, is, of course, exceedingly rare. If we do not know the relation of volumes between the two rocks, other ways must be sought for, at least, a partial solution of the problem. If we know that one or more new constituents have been added, we may subtract these, recalculate on 100, and then compare the analyses. This method in many cases leads to fairly correct results, but it must be applied with the understanding that, ordinarily, it will only give approximate results; and that, if there be many partial additions and subtractions, the inaccuracies may be very great, and actual losses and gains may appear reversed.

If we know that one constituent has remained constant, with neither gain nor loss (as the silver in the example cited above), then correct results may be obtained by recalculation on this assumption, as has been shown. This mode of calculation has been used by Scherer, J. Roth, and lately also by Prof. G. P. Merrill, in his book on "Rocks and Rock-Weathering." It is only rarely, however, that we are able to recognize this constancy, for nearly all constituents undergo some change in the alterations of wall-rocks. Even alumina, often considered to be nearly insoluble, shows great changes in some altered rocks. Besides, if we base recalculation on some compound of which

but a small percentage is present, the multiplication of errors may play havoc with the result. Altogether, this mode of ascertaining gains and losses must be applied with the greatest caution.

Any given analysis of fresh and altered rock may correspond to several very different mineral compositions. For any given mineral composition, the constancy of one constituent during the change to another (also known) mineral composition, determines the change in volume involved (not considering porosity). When the change in volume can be directly ascertained, we are definitely able to obtain the absolute gains and losses suffered by unit-volume of the rock, and this comparison is ordinarily the one which throws most light on the processes involved. But relations of volume are difficult to obtain with certainty, especially in regard to a rock made up of a number of minerals which have suffered different changes. As a rule, in fissure-veins, the replacing minerals are denser than those replaced, so that, if the rock remained compact, there would be a decrease in volume. But as there usually are no indications of compressive stress in the altered rock, the result of this replacement of lighter by heavier minerals will be a porosity expressed by a notable difference in the experimentally determined specific gravity of the rock and that calculated from its known mineralogical composition. This may, in some cases at least, justify the assumption that the rock has not changed its volume as a whole; and if this be true, a direct comparison between equal volumes of fresh and porous altered rock is practicable. Should it appear probable that an actual change of volume has taken place, either by expansion or contraction, it will ordinarily be a difficult matter in each case to ascertain the exact amount of this change, without which knowledge the calculations cannot be carried out. If there is porosity, the changes by unit-weight of original substance may differ greatly from those obtained by unit-volume, hence porosity is a factor which must not be overlooked. One method may indeed indicate the very opposite of the other. For instance, by the first way, it may be ascertained that a rock has gained several per cent of its weight; while the other method may show that an actual loss per unit-volume of original rock has taken place.

In the considerations outlined above, it is assumed that the rocks to be compared have undergone no change of volume since their removal from the surrounding mass. In regard to the fresh rocks, there is, as a rule, little fear of this. Certain altered rocks, however, easily soften or crumble when exposed to the air, probably indicating that an increase in volume is taking place. An exceedingly slight action of this kind would evidently be sufficient to break up the rock if it were not confined. There is, therefore, little reason to fear that such change of volume has taken place, if the specimens of altered rock remain firm and solid.

Criteria of Metasomatism.

Considerable space was devoted to this subject in the discussion of Posepny's paper in the Transactions of the Institute,⁴ and it may therefore be passed with brief notice.

It is not always easy to be sure whether metasomatic action really has taken place, and in deciding this question the greatest caution must be observed. The mere occurrence of two minerals together by no means proves that one has been derived from the other. The chief difficulty is to draw the distinction between molecular processes involving simultaneous dissolution and precipitation, on the one hand, and previous dissolution and subsequent precipitation on the other.

The only decisive criterion is that of metasomatic pseudomorphism, involving the proof (generally to be furnished by microscopic study) as to whether simultaneous dissolution and deposition have actually taken place. The most satisfactory proof is the distinct alteration of well-defined crystals (or, at least, well-defined grains) of the original mineral into the secondary mineral, in such a way that the latter projects into the former in prisms or fibers, having crystalline outlines. Another proof is afforded by sharply defined crystals of the secondary, embedded in the primary mineral, without any break between their surfaces; but in this case it must be clear that the replacing mineral is really secondary, and was not formed before the primary. Another satisfactory proof is given when, for instance, in a sandstone, the newly formed mineral has in part

* *Trans*, xxiii, 587

a crystalline form, and its surfaces squarely intersect the grains of clastic material which it partly replaces

There are many other available criteria such as the enlargement of fissures in the replaced mass. An instance is shown in Fig. 30, representing a veinlet of quartz formed by filling a small open fissure, and adjoined on one side by galena, which extends most irregularly into the adjoining quartzite. (See also Fig. 28⁺) The retention of the structure of the original mass by the secondary replacing minerals is also an excellent criterion, provided it be identified beyond doubt. Thus, for example, certain porphyritic rocks have suffered nearly complete silicification, but preserve almost entirely the outlines of phenocrysts and the structure of the ground-mass. The occurrence of remaining *nuclei* of unaltered rock is sometimes an available criterion; but it must be used with caution, and probably has given rise to misinterpretations, on account of its similarity to actual inclusions of country-rock in vein-filling. In cases of replacement by sulphides, the unaltered residual rock may be sharply defined, and may closely simulate inclusion. In cases of replacement by calcite or quartz, there is less of this danger, as the action is usually more gradual. If the alteration or replacement proceeds normally from the outside of a crystal or angular mass of rock, the tendency will be towards rounded residual portions in the interior of the mass, as may often be seen in altered crystals of olivine. This criterion for replacement, suggested by G. F. Becker, may under circumstances prove useful. Generally, however, the replacement proceeds very irregularly, owing to the effect of little cracks and fissures. Slight clay-seams may often interpose an absolute barrier, so that sharp contacts of replaced and fresh rocks result. The replacement of crystals or angular fragments may occur without changing in the least, even by the rounding of corners, the form of the masses.

In conclusion, I would repeat and adopt the statement of Mr. Becker,[†] that "the theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic, molecular replacement."

⁺ A somewhat similar and excellent illustration is given in Rickard's "Vein-Walls," *Trans.*, xxvi., 195, from the Hillside mine, Arizona

[†] Discussion of Posepny's paper, *Trans.*, xxiii., p. 602

In many fissure-veins, practically all of the economically important ore has been formed by replacement; and for these deposits the term *replacement-veins* is especially used. But if we do not confine ourselves to the fluctuating definition of "pay-ore," practically all fissure-veins are, to some extent at least, replacement-veins.

Mr. Enmons¹ has suggested the following criteria for "*replacement-veins*" in the narrower sense of the word: (1) absence of symmetrical banding or comb-structure in the vein-material, and of breccias of country-rock, cemented by vein-material, (2) great irregularity in the width of the ore-bodies, which may reach very great dimensions; (3) general lack of definition between ore-body and wall-rock.

Crystallization of Secondary Minerals in Other Bodies.

It has been known for a long time that perfect crystals of minerals, such as quartz, for instance, may be formed in soft rocks such as shale, limestone, clay, etc.; but concerning their exact mode of formation there has been considerable difference of opinion. Probably the prevailing view, some 20 years ago, was that the growing crystal had, by means of its force of crystallization, pushed apart the surrounding mass. This was indeed the opinion of von Groddeck, who declares† that the formation of a completely developed crystal in a solid, rigid mass is not possible. Apparent exceptions, such as magnetite in chloritic schists, he considers as caused by development, while the rock was soft, under the influence of metamorphic agencies. There is no doubt good foundation for this view; for in magmas and solutions crystals may grow to perfect development, and if, for instance, a saturated solution of ferrous sulphate is mixed with some neutral fine powder to a soft pulp, extremely clear and sharply developed crystals of this salt will separate out.

But it has gradually become apparent that it is not necessary to assume complete permeation and softening of a rock by concentrated solutions, in order to account for secondarily-developed crystals. It is now well known that the secondary development of crystals in solid material is not only a possible

* *U S Geol Surv*, Folio 38, on Butte, Montana.

† *Die Lehre von den Lagerstätten der Erze*, Leipzig, 1879, p. 68.

but an exceedingly common phenomenon, and that it may be caused by simple metasomatic replacement of the surrounding material.

The mechanical force of crystallization probably co-operates, to some extent, with the chemical agencies of replacement; and when the surrounding mass is thoroughly softened and saturated by the depositing solutions, the former force may be alone active. The growing crystal may include parts of the surrounding rock, as is seen in Figs 3 and 4, representing calcite in quartz, and in Fig 27, showing inclusions of sericite in pyrite. This is analogous to, but not identical with, the occurrence of inclusions of fluid and glass in crystals separating out from solutions or magmas. It is not uncommon to find new crystals of perfect development generated in a grain of another substance, such as quartz or feldspar, without any disturbance of the optical orientation of the older minerals, such as unfaillingly would occur were the process simply one of mechanical force. No doubt the exchange of substance takes place through the medium of a film of water, but this is generally so exceedingly thin that the strongest powers of the microscope fail to reveal it. In many cases, however, the new mineral begins to grow on the planes of small fractures, traversing the original mineral. Fluid inclusions accumulate on this plane; and the first separation of the new mineral appears as little dots, closely connected with the inclusions. No doubt the line between metasomatism and cavities of dissolution subsequently filled is a very fine one, and difficult to draw in many cases; but when intermediate cavities or subsequent fillings cannot be traced with the microscope, the process may be classed as metasomatic; and in the great majority of cases this interpretation will be correct.

Secondary Alteration of Veins.

Under any given conditions, minerals tend to assume the forms most stable under those conditions. Since the conditions prevailing during vein-formation are very different from those prevailing afterwards, it may be inferred that the products of the first process might easily be changed. Such is indeed the case. We find many altered rocks which have evidently undergone more than one change. Especially near the surface,

under the influence of oxidizing waters, the minerals formed in the rocks along veins are apt to suffer great changes. Examples are frequent, showing that the minerals which filled the open spaces along a vein have been completely dissolved and partly or wholly replaced by others. This is particularly true of fillings of calcite or barite. Many instances are known in which large masses of these minerals have been completely dissolved and replaced by quartz. Such are the well-known deposits of Schneeberg in Saxony, and those of the De Lamar mine in Owyhee county, Idaho.

Structure and Composition of Metasomatic Vein-Rocks and their Relation to General Metamorphism.

The aggregates replacing the original wall-rocks of veins show great variety of structure. It is most common, perhaps, that the structure of the resulting rock is much finer than that of the primary. As examples may be cited silicification, which nearly always results in microcrystalline and cryptocrystalline aggregates, and sericitization, which generally results in a mass of very fine tufted fibers. This is not, however, a general rule; because certain easily soluble minerals, when replacing others, produce a much coarser aggregate than that of the original rock. Of such character, for instance, are the carbonates. (See Fig. 27.) Fluorite replacing limestone (see Fig. 14) is another instance of coarser grain shown by the secondary rock.

As a general rule, the resulting minerals have, on the whole, a greater aggregate specific gravity than the original minerals. Muscovite, sericite, fluorite, the different carbonates, pyrite and other sulphides (as well as topaz and tourmaline, so abundantly formed in tin-deposits) are instances. On the other hand, there are exceptions, such as the development of jasperoids and other quartzose rocks from limestone, in which case the resulting material has less specific gravity than the original.

A banded structure of the altered rock may possibly, as mentioned above (p. 590), result from replacement by sulphides in a sheared rock, in which the shear-planes are closely spaced, but this banding is not likely to be as well marked as the crustification often caused by the gradual filling of open spaces. From these two sorts of banding a third must be differentiated, namely, the typical "ribbon-structure" caused by shearing of

the already-formed vein, in connection with which a secondary concentration of gold and sulphides may have taken place on the shear-planes—whence the richness of vein-material often associated with this structure

In no case, thus far, has any law of progressive alteration of the country-rock of a vein been detected, which would enable us to say that the intensity of the process either increases or decreases from the surface down. Nor has any instance been shown in which the processes of alteration permanently change with increasing depth. This does not exclude the fact that occasionally a different subordinate process of alteration may be introduced. It is known, for instance, that certain parts of the rock near the vein may be locally silicified, although the principal and prevailing process in depth, as well as near the surface, is of a totally different character. Thus, silicification and the formation of greisen may occur side by side in cassiterite veins, and silicification and carbonatization in cinnabar veins.

The metasomatic processes in wall-rocks of fissure-veins differ generally from those of regional (static and dynamic) metamorphism. In most cases oxides of iron and manganese such as magnetite, hematite, ilmenite and pyrolusite, are absent as a primary development, and many silicates, exceedingly common in static and dynamic metamorphism are, as a rule, missing in veins. Among these are amphibole, biotite, garnet, cordierite, serpentine, ottrelite, and zoisite. Chlorite and epidote are confined to the vicinity of only one or two classes of veins. Albite, exceedingly common in regional metamorphism, is not known as a metasomatic development in veins, though, like orthoclase, it may occur in the filling of open cavities. Muscovite, calcite, quartz and pyrite are common to both kinds of metamorphism. As compared with the products of contact-metamorphism, we note in metasomatic vein-phenomena a total absence of the pyroxenes, wollastonite, staurolite, cyanite, andalusite, vesuvianite and garnet. Only two classes of veins are characterized by tourmaline, which is a frequently occurring contact-mineral. Again, as compared with the results of ordinary hydro-metamorphism, we note in the results of metasomatic vein-action the scarcity of amphibole as well as of zeolites, except in one or two classes of veins, and also the relatively slight importance of chlorite and epidote.

The degree of hydration in altered vein-rocks is very moderate, and in some cases, as, for instance, in the change of serpentine to magnesite, there is a distinct dehydration. Strongly hydrous minerals are not common on fissure-veins.

I have emphasized these differences, to show that the metasomatic processes in veins cannot simply be identified with those that were active in the other phases of metasomatism mentioned. In the majority of cases, the vein-processes have a distinctive character of their own.

PART II.

MINERALS DEVELOPED BY METASOMATIC PROCESSES IN FISSURE-VEINS.

Quartz (including Chalcedonite and Opal).—Though silicic acid is weak, and cannot under ordinary circumstances expel even carbonic acid from its compounds, it is easily deposited instead of other minerals, which are dissolved by more active reagents contained in the same waters. Hence the frequency of quartz in the forms of other minerals. It would be erroneous to say, however, that silicification is a very common metasomatic process, even in veins containing quartz as a filling; and very rarely is it the exclusive process in any given vein. It is most common in limestone and other easily soluble rocks, also in such porous rocks as sandstones, though here it is usually to be regarded rather as cementation. In rocks rich in silica, such as rhyolite or quartzite, the tendency to silicification (probably by reason of mass-action) is greater than in more basic rocks in the same district.

Quartz replacing limestone along fissures is a common occurrence. The process usually results in a microcrystalline or cryptocrystalline aggregate of interlocking grains, preserving the original structure, as shown in Fig. 1,* which represents a silicified limestone from the Diadem lode, Plumas county, Cal., and shows the remaining outline of a foraminiferal test. The development of the quartz is shown in Figs. 3 and 4,† represent-

* After H. W. Turner, *Journal of Geology*, vol. VII, No. 4.

† The accompanying figures, with some exceptions noted in the list, were drawn by myself under the microscope, with camera lucida.

ing rocks from Aspen, Colorado.¹ Small secondary grains or well-developed crystals appear in the limestones and, gradually extending, finally produce an aggregate which, in this case, is somewhat coarser than in the rock from California. Quartz crystals with double terminals may occur in metasomatic rocks, but are foreign to quartz, filling open cavities. Opal and chalcedonite may occasionally also be present. The resulting fine-grained rocks, often stained brown or red, may, according to Mr. Spurr's proposal, be called jasperoids.

Daubrée describes heavy quartz veins, cutting through granite and overlying sedimentary rocks, in the Central Plateau of France.[†] Besides quartz, these veins carry fluorite, barite, calcite and galena. Agate and jasper in banded form are also frequently present. From the same description,[|] it appears that in some places, where these veins traverse limestone (*Muschelkalk*), there has been a very strong silicification of the enclosing rock, as is proved by means of the occurrence of crinoids in the compact quartz now forming part of the lode. Another locality, also in the Vosges, is mentioned as showing a large deposit of fine-grained hornstone-like quartz, also containing barite and fluor-spar, and full of little geodes with projecting crystals of quartz. In this siliceous rock, silicified shells of *amula* and *pecten* have been found, showing its derivation from the surrounding limestone. The chemistry of the process is apparently simple: waters containing carbon dioxide and silica deposit the latter, while simultaneously dissolving a corresponding proportion of calcite.

In contrast to the fine-grained structure of jasperoids, quartz deposited in open spaces is usually characterized by coarse grains, the majority of which show partly developed crystal-faces. Crystals developed at both terminals do not appear, though earlier-developed individuals, growing from some deposit, are surrounded by later-developed grains. Fig. 2, which shows the normal structure of the quartz in the California gold-veins, illustrates this occurrence.

* The thin sections from which these figures were made were kindly loaned to me by Mr. J. E. Spurr.

† Daubrée, *Les Eaux Souterraines aux Époques Anciennes*, p. 124.

‡ *Loc. cit.*, p. 151.

Quartz may further replace orthoclase, as shown in Fig. 5, with preservation of the crystal-form. The ordinary course of alteration of the latter mineral is to quartz, sericite, or kaolinite, and potassic carbonate. In complete replacement by quartz, the alumina and potassa have been carried away, and the quartz has received a considerable addition. The process may also be explained as a complete replacement, by means of which the orthoclase, as such, has been removed, and quartz has been deposited. In the same manner, soda-lime feldspars may be replaced by quartz, as well in phenocrysts as in the ground-mass. Even the ferromagnesian silicates may suffer a similar change. A partial replacement of hornblende by quartz and chlorite (Fig. 6) is common. The ground-mass surrounding crystals of quartz in certain rhyolites (Silver City and De Lamar, Idaho) may be replaced by quartz, forming a secondary aureole around the primary crystal.

Under favorable and very exceptional circumstances, veinlets containing coarser quartz, simulating comb-quartz in structure, may be formed by replacement. Fig. 7 represents a contact between chloritic basalt and silicified rhyolite, on which a small quartz vein is developing, the crystals replacing the ground-mass of the silicified rhyolite.* Replacement of minerals by chalcedonite and opal instead of by quartz is less common. Near cinnabar veins, in California and elsewhere, serpentine, transformed into opal, with retention of the primary structure, has been observed.

Rutile and Anatase—These minerals are common in metasomatic vein-rocks, as secondary products after ilmenite, titanite, titaniferous magnetite, biotite, etc. Rutile occurs in nearly every altered titaniferous rock; anatase (octahedrite) has been found in the altered rocks of Freiberg (Stelzner), Nagyag (Kollbeck), Schwarzwald (Sandberger), and Silver Cliff (Cross). Neither titanite nor ilmenite appear to be stable under the influence of vein-forming solutions. In several publications† I have assumed that the milky white flocculent mass (leucoxene) which often results in vein-rocks from the alteration of titaniferous minerals is titanite, but this assumption now appears to

* 20th Ann. Rept. U. S. Geol. Surv., part iii, p. 186.

† 14th Ann. Rept. U. S. Geol. Surv., part ii, p. 276, *et seq.* 17th Ann. Rept. U. S. Geol. Surv., part ii, p. 149, *et seq.*

be incorrect. The substance is certainly free titanio acid, as shown by the fact that no titanium is extracted by hydrochloric acid, while the mineral is attacked by boiling sulphuric acid.

Fluorite.—This mineral may replace many others. It has generally a purplish, unevenly distributed color, and shows under all circumstances a strong tendency to crystal-development. Its formation from limestone is illustrated in Fig. 14, which represents the contact of one of the many small nodules of fluorite scattered in a limestone breccia from a mine in the Judith mountains, in Montana*. The sharp angles of the cube will be seen projecting into the limestone, the latter contains many imperfect fossil shells, and some crystals of secondary quartz.

While the reaction involved in this process is not clearly established, it is probably a complete replacement, the more soluble calcite being taken up by the waters and the less soluble fluorite simultaneously deposited.

Fluorite, together with quartz and pyrite, is further formed as a replacement-product of orthoclase, as shown in Fig. 10, representing a feldspar grain from a breccia in the Independence mine, Cripple Creek, Colo. The replacement of some of the phonolite and fine-grained granite-andesite breccia from Cripple Creek has resulted in a large quantity of crystalline fluorite and quartz (Fig. 9). Wherever calcium silicates are present, and the waters contain sodic fluoride, the result will be sodic silicate and calcic fluoride. In this way the mineral may be formed by interchange of constituents†. Alkaline fluorides and calcic fluorides may exist together in the same solution; but alkaline carbonates decompose fluorite, yielding alkaline fluorides and calcic carbonate; hence fluorite cannot exist as such in waters containing alkaline carbonates.

Calcite.—This mineral and the allied magnesian and ferrous carbonates are exceedingly common in metasomatic vein-rocks, and their occurrence gives testimony of the energetic altering action of carbon dioxide and alkaline carbonates on nearly all silicates. The metasomatic calcite is of fine or coarse grain—the latter especially when replacing easily soluble minerals. It

* This section was prepared for Mr. W. H. Weed, who kindly allowed me to use it.

† Bischof, *Chem. Geol.*, Bonn, 1861, ii, p. 95.

has very little tendency to crystallize, nearly always occurring in irregular grains

Calcite replaces quartz to a greater or less extent, though in rocks containing also silicates like feldspars and hornblende, these minerals are first attacked, and the replacement of the quartz is usually only partial. The quartz is evidently dissolved by waters containing alkaline carbonates, and a corresponding quantity of calcic carbonate, also dissolved in the water, is deposited in its place. Under ordinary pressure and temperature, water does not dissolve quartz, but increase of either results in solution to some extent. The presence of carbon dioxide alone does not promote the solubility. No pseudomorphs of calcite after quartz are known—an evidence of the resistance of the latter mineral to solution.

The replacement of quartz by calcite in granitic rocks is shown in Figs 13 and 15. The calcite, developed along cracks and fissures, spreads and corrodes the original substance. Small masses of sometimes rhombohedral calcite project into the quartz. Rounded and isolated bodies of calcite may also form on inclined fracture-planes, by extension they finally join and form larger masses.

Orthoclase is likewise replaced by calcite in many granitic rocks adjoining veins. The process is similar to the replacement of quartz; but the feldspars are much more easily soluble than quartz. Chemically, the process, as already pointed out by Bischof,* may be considered as simply due to the attack of waters containing calcic bicarbonate. The carbon dioxide of the latter alters the orthoclase, the resulting alkaline carbonates and silica are carried away; just in what form the alumina is removed is not certain. In the majority of cases a simultaneous formation of sericite occurs, so that the actual loss of Al_2O_3 may be very small. Even more easily effected is the replacement of soda-lime feldspars by calcite, for here the original mineral contains one of the constituents of the result. As is well known, andesine, labradorite and anorthite may be partly converted into calcite under the influence of ordinary cold waters containing carbon dioxide.

In the same manner, it is common to find pyroxene, amphi-

* *Chem. Geol.*, 11, p. 428.

bole and biotite partly converted into calcite. In vein-forming processes, these are usually the first minerals to suffer from the attack. The magnesia, alumina and ferrous oxide usually remain in the form of chlorite or other secondary silicates, though some of the magnesia and iron may also form carbonates.

Magnesite and Dolomite—Small quantities of magnesian and ferrous carbonates nearly always combine with the newly formed calcite, but in many cases are of no special importance.

A change of limestone to magnesite is not known as a vein-forming process. Dolomitization commonly occurs, however, in limestones adjoining fissure-veins, as, for instance, described by Spurr* at Aspen, Colorado. At this place, as the dolomitization proceeds irregularly from the fissures, the coarse calcite grains are broken up into smaller rhombohedral crystals, of the yellowish tinge characteristic of dolomite. The process is clearly one of metasomatic replacement, carried on by waters containing magnesian bicarbonate, or even chloride. The correctness of this view has been shown by synthetical experiments.†

Mr. Spurr shows convincingly that ordinary circulating surface-waters do not dolomitize the limestone which they traverse. The reagents which produced this dolomitization must have been more potent. Several hot springs in the vicinity of Aspen, Colorado, carry carbonates of lime and magnesia, and also a large amount of sodium chloride and magnesium chloride. These waters, as shown by analyses, have a distinct dolomitizing influence on the adjoining limestone. The change is also accompanied by silicification and ferration.

Dolomitic carbonates may also partly replace albite, as shown by Mr. H. W. Turner‡ in the case of a mineralized dike of albite rock from Tuolumne county, Cal. An accompanying almost pure magnesite may possibly have resulted from the alteration of the adjoining serpentine.

Magnesite and dolomitic carbonates are very apt to form from serpentine, as illustrated in the country-rock adjoining the Idaho vein, Grass Valley, Cal § The fine-grained serpentine is trans-

* Monograph XXXI, *U S Geol Surv*, p 210

† Doelter, *Allgemeine Chemische Geologie*, Leipzig, 1900, p. 158.

‡ *Journal of Geology*, vol. vii, No 4, p. 313

§ W Landgren, 17th Ann. Rept. *U S Geol Surv.*, part ii, p 153.

formed into a coarse-grained magnesite, mixed with quartz and some residual serpentine (Fig 26). The composition of the altered rock is

	Per cent
Magnesian carbonate,	34.78
Calcic carbonate,	8.22
Quartz, . . .	26.00
Serpentine (with chlorite),	31.00
	<hr/> 100.00

The chemical action involves a substitution of CO_2 for SiO_2 ; the latter being deposited in the rock.

Siderite —This mineral is less common in altered rocks than the other carbonates. At Aspen, Colorado, Spurr mentions it as forming small rhombohedrons in silicified limestone. In the lead-silver veins of Wood River, Idaho, it replaces calcareous shales. In the lead-silver veins of Cœur d'Alene, Idaho, it replaces the clastic quartz of quartzite in the most energetic manner and abundant quantity (Figs 16 and 17). The siderite has strong tendency to crystal development; and the rhombohedral crystals often cut squarely across the quartz grains which they partly replace (Fig 18). To explain the chemistry of this process, we must suppose waters exceedingly rich in alkaline and ferrous carbonates and poor in silica. SiO_2 must be dissolved and FeCO_3 simultaneously deposited.

Muscovite and Sericite —These two names practically signify the same mineral, though sericite is employed for the fine-grained or fibrous and tufted modifications, resulting from the replacement of other minerals. Sericite is probably the most universal and abundant of all minerals forming in altered rocks near fissures. Only a few classes of ore-deposits, namely, those in limestone and those in recent volcanic rocks, involving propylitic alteration, are comparatively free from it. A vast proportion of so-called "talc," "clay" and "kaolin" is really sericite.

Sericite forms from quartz in many rocks, though this action is less intense than in the case of the silicates. Foils and fibers of the secondary mineral may develop along cracks, or may intrude, sharply defined, into the quartz, from the outside of the grain. Complete pseudomorphs after quartz are rare. A complex chemical action is probably involved, as sericite is practi-

cally insoluble. A transportation of potash and alumina must be assumed, though in what form the latter oxide was in solution is not clear. The dissolved quartz may be directly combined with these two constituents. It is often observed that the replacement of the quartz is most active when, together with the sericite, calcite is formed (Fig. 15).

As is well known, sericite forms easily and abundantly from orthoclase and microcline, the foils and fibers developing on cleavage-planes and cracks, until they invade the whole crystal. The reaction may be chemically expressed as follows, water containing carbon dioxide being the only reagent necessary



This reaction is accompanied by a considerable reduction of volume, the sericite occupying less than one-half of the original volume of the orthoclase. If SiO_2 separates as quartz, the aggregate volume of the two secondary minerals shows a reduction of 13 per cent from the volume of the orthoclase. Very often, however, the quartz is carried away in solution, to be deposited in neighboring open spaces. Calcite is frequently deposited together with sericite in the feldspar (Fig. 12). Though it is usually fine-grained, large foils may sometimes be formed. Fig. 19 shows radial muscovite forming, together with kaolinite from orthoclase, in the orthoclase of granite adjoining a fissure, in which thermal waters at the present time are depositing a vein.*

Sericite forms with equal ease from oligoclase, andesine and labradorite, as from orthoclase, and calcite usually also accompanies it. This interesting fact was first described, I believe, by Bischof,† who also furnished the chemical explanation. The potassic carbonate contained in the water changes the sodic silicate into potassic silicate, which unites with the aluminum silicate to sericite. This will result in a progressive elimination of soda and introduction of potash. In the same manner potassic carbonate decomposes calcic silicate, replacing lime with potash. Bischof gives an excellent illustration of this by describing the surface alteration of a knife of the "stone age," originally made from some flinty rock.

* Kindly furnished by Mr. W. H. Weed.

† Bischof, *Chem. Geol.*, 1., p. 31, et seq., also p. 44.

Even pyroxene and amphibole may alter to sericite, as is frequently shown in the metasomatic vein-rocks of California gold-quartz veins. The explanation is on the lines of the reactions just described. The resulting sericite is often coarsely fibrous.

Biotite alters very easily to coarse muscovite, with loss of magnesia and iron, and separation of rutile (Fig 27)

An instance of replacement of andalusite by muscovite is shown in Fig. 20. Few analyses are available, indicating the exact composition of the sericite contained in metasomatic vein-rocks; but the satisfactory results obtained from the calculation of many rock-analyses on the basis of molecular ratio, closely corresponding to the composition given below, leave little room for doubt that the sericite is practically identical in composition with a normal muscovite

Prof. Beek, of Freiberg, has had the kindness to give me an unpublished analysis, made by Dr. H. Schulze, of a white mica, separated by Prof. Stelzner by heavy solutions from the altered country-rock adjoining the Dietrich Stehenden, Morgenstern Erbstolln, Himmelfahrt mine, Freiberg. This analysis is as follows

	Per cent
SiO ₂	47.48
TiO ₂	trace
SnO ₂	0.02
Al ₂ O ₃	35.16
Fe ₂ O ₃	1.92
CaO	0.48
MgO	1.11
K ₂ O	10.08
Na ₂ O	0.41
H ₂ O	4.02
	<hr/> 100.68

As minerals most closely related to muscovite, we may mention zinnwaldite, containing much fluor and lithia, which replaces feldspar in granite near cassiterite-veins; also mariposite (fuchsite), containing chromium, which, with magnesite, apparently replaces serpentine and allied rocks at Nevada City, and on a much larger scale at many places along the Mother Lode of California

Biotite—Exceedingly common in the form of metamorphism, biotite appears but rarely in fissure-veins. Replacing horn-

blende and feldspars, it is found as small scales in veins carrying tourmaline (Meadow Lake, Cal.), replacing the same minerals, it appears abundantly in the gold-copper veins of Rossland, B. C. A greenish mica, probably biotite, occurs, replacing quartz, in small veinlets, associated with quartz, garnet, tourmaline, actinolite and zinc-blende, in the Bunker Hill and Sullivan mine, Idaho. Prof. Penrose reports secondary biotite forming in the Ocean Wave mine, Cripple Creek, Col. Under the influence of waters containing carbon dioxide or alkaline carbonates, biotite is not stable.

Chlorite.—This mineral, replacing amphibole, pyroxene and biotite, is commonly found in altered vein-rocks, but ordinarily it is only a transition-form, often abnormally rich in iron, which these minerals assume, under the influence of waters slightly charged with carbon-dioxide, before their final conversion into sericite and carbonates. The chlorite has the ordinary fine fibrous character and shows a strong tendency to migrate into adjoining minerals. In the case of biotite, the conversion should normally result in chlorite, ferrous carbonate, potassic carbonate and silica, in that of amphibole or pyroxene, calcic carbonate may form beside chlorite. Pseudomorphs of chlorite and quartz after hornblende are, in fact, very common (Fig. 6). The chloritic alteration is most important in the group of the propylitic veins. Possibly, under the influence of strong alkaline carbonates and carbon dioxide, chlorite cannot exist. G. F. Becker mentions chlorite as enclosed in vein-quartz from some localities in the Southern Appalachians, and also in gold-quartz veins from Funtler's Bay and Admiralty Island, Alaska. I have described a similar occurrence in an abnormal vein, from Crown Point mine, Grass Valley, Cal. But, on the whole, it is not a common mineral in vein-fillings.

Pyroxene and Amphibole.—These minerals are, as a rule, foreign to fissure-veins, and entirely absent from gold- and silver-veins characterized by sericitic alteration. Amphibole has been noted in the filling of certain copper-veins. Some of these are more or less intimately connected with contact-metamorphism; others, like the copper-veins of Rossland, B. C., have probably been formed under dynamic-metamorphic conditions. It occurs also in small veinlets of abnormal character, containing garnets, in the Bunker Hill and Sullivan lead-silver mine, Idaho. Rhodonite, a bisilicate of manganese allied to pyr-

oxene, does, however, occur in many veins as part of the filling (Butte, Montana, Real del Monte, Mexico, Kapnik, Hungary, Broken Hill, Australia).

Garnet.—This mineral is very rare in fissure-veins, though common in dynamic and contact-metamorphism. Mr S. F. Emmons¹ states that it replaces limestone at Clifton, Arizona, apparently as a part of the phenomena of mineralization. As part of the filling of gold-quartz veins, it is reported by G. F. Becker† from several localities in the Southern Appalachians. The remarkable occurrences of Broken Hill, N. S. W., should be mentioned here. From the extensive literature‡ it is apparent that opinions differ somewhat widely with regard to these interesting deposits.

The deposits of the Barrier ranges near Broken Hill are probably fissure-veins, occurring in crystalline schists of various kinds, perhaps chiefly a garnet-gneiss. Broken Hill Proprietary lies parallel to the schistosity, and may, according to some, be considered as a saddle-reef. Other veins, such as the Broken Hill Consols, cut the schistosity in strike and dip. The ores are galena, zinc-blende and rich silver-ores. The gangue in the Proprietary mine is chiefly garnet, with quartz, opal and rhodomite. In the Consols and other veins, siderite and calcite also appear, besides quartz and garnet. If veins, as seems most probable, they represent a decidedly novel type. The sulphides, to some extent, replace other minerals. (See under *Galena*, below.)

Epidote.—This mineral, so common in regions of static and dynamic metamorphism, is not abundant in the altered rocks of fissure-veins, or in the filling of open spaces. When it occurs, it has a deep yellow color, contains much iron and develops in irregular grains, or into radial bunches of imperfect crystals. It occurs chiefly in basic rocks containing labradorite and similar soda-lime feldspars, and may form pseudomorphs after orthoclase, plagioclase, hornblende or augite. In altered vein-rocks, epidote and muscovite rarely occur together. Epidote contains much ferric oxide, and can hardly be formed

* Unpublished observations.

† 16th Ann. Rept. U. S. Geol. Surv., part iii., p. 276.

‡ J. B. Jaquet, *Mém.* 5, *Geol. Surv. of N. S. Wales*, Sydney, 1894; George Smith, *Trans.*, xxvi., 69, 1896; R. Beck, *Zeitschr. f. prakt. Geol.*, March, 1899, etc.

under strong reducing influences. It does, however, not follow that it must have been formed under oxidizing conditions; for rocks ordinarily contain much ferric oxide, and pyrite has often been observed embedded in epidote. Epidote is found in the veins of Lake Superior which carry native copper; in some veins characterized by tourmaline (Fig. 21); and, finally, in the metasomatic rocks accompanying the propylitic Tertiary gold-silver veins.

Orthoclase.—As a product of thermal alteration, orthoclase does not commonly appear, and has not been recognized until lately. Closer search will probably reveal it in many altered rocks and vein-fillings of the propylitic type. When forming, it has always a strong tendency to crystallize, and in thin sections usually appears with rhombic, sharply defined outlines. The crystal form is similar to that of adular, though the basal plane is small or entirely wanting; the prisms and dome being the only prominent faces. For this variety, occurring in fissure-veins, the revival of the name of valencianite is suggested, proposed by Breithaupt for the mineral as occurring in the Valenciana silver-mine, Guanajuato, Mex. In certain propylitic gold-silver veins (Silver City, Idaho; La Valenciana, Mex.) valencianite is prominent as part of the filling of open spaces. In the copper-bearing veins of Lake Superior, orthoclase replaces prehnite, and is deposited on datolite, calcite, analcite and quartz. In connection with the occurrence of adular at St. Gothard, this mineral is found on calcite. At Bergen Hill, N. J., the Mesozoic diabases are traversed by veins (1 to 4 inches thick) of quartz and orthoclase, associated with various zeolites, galena, chalcopyrite and pyrite. At Cripple Creek, Colo., orthoclase is an important vein-mineral, occurring partly as a coating of cavities of dissolution in granite (Fig. 11), partly in metasomatic development after many minerals in granite-andesite breccia and phonolite. Orthoclase and calcite have apparently been formed together in certain metasomatic rocks from Cripple Creek, Colo.

Orthoclase has been reproduced artificially by the action of potassic silicate on muscovite at 500° C., but it is evident from many occurrences that a much lower temperature is sufficient for its formation in fissure-veins. In the Silver City, Idaho, veins, for instance, the temperature cannot have been much higher than 100° C. during the deposition of the mineral.

Albite.—Though known as a vein-filling, together with quartz, at many places, for instance, in many California gold-quartz veins, this mineral has not been observed hitherto replacing other substances. In metasomatic rocks resulting from other metamorphic processes it is, as is well known, very abundant.

Tourmaline.—This very complex silicate of aluminum, magnesium, ferric iron and sodium contains also about 10 per cent. of boric acid, as well as a little combined water and fluorine. In metasomatic development, it forms irregularly massed crystals, or single crystals impregnating the mother-mineral. Its tendency to crystallization is very strongly marked. It replaces orthoclase and plagioclase, as well as quartz, but is not known to be formed from ferromagnesian minerals. As shown in Fig. 21, small almost perfect crystals may develop in the feldspathic substance, without disturbing its optical orientations. Similar development in quartz is illustrated in Fig. 23. In fine-grained elastic rocks like slate, tourmaline may also form. The only occurring variety is black, usually showing dark brown and dirty bluish or greenish colors in thin section. Tourmaline often occurs in large masses of small felted individuals, together with quartz, entirely replacing the original rock.

The mineral is confined to cassiterite-veins and to the allied group of the gold-copper-tourmaline veins. It is not usually associated with carbonates, and the occurrence of siderite with tourmaline, described by von Fircks from Tasmania,* is therefore of special interest.

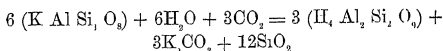
Topaz.—This fluosilicate of aluminum, containing besides, according to the latest investigations, some chemically combined water, is confined to the cassiterite-veins. It usually appears abundantly in the altered rock next to these veins, replacing the feldspar and even the quartz,† as well as the groundmass of porphyritic rocks. The new-formed topaz may appear in irregular grains, but is often partly crystallized, and then appears in radial masses. The formation of topaz from orthoclase is analogous to kaolinization, silica and potassa being set free. But fluorine is also introduced, which points to another agent than carbon dioxide as active in this reaction. It has been artificially reproduced by the action of hydro-

* *Zeitsch. d. d. geol. Ges.*, Bd. 11., p. 443, 1899.

† *Loc. cit.*, p. 444.

fluosilicic acid on silica and alumina. Topaz is not very stable. It is easily altered to kaolinite or sericitic minerals.

Kaolinite—The hydrous silicate of aluminum was formerly supposed to occur very extensively in altered vein-rocks, but it has been shown that the larger part of the minerals considered as kaolinite or as "talc" are really sericite in finely divided form. Kaolinite forms from orthoclase, albite or sodalime feldspars, with liberation of silica, the reaction in the first case being expressed as follows



Ferromagnesian silicates, and even quartz, may be converted into kaolinite, as is shown by the altered rock adjoining a recent vein near Boulder, Montana. The mineral is nearly always in an extremely fine state of distribution, the aggregates have a very low bi-refracting power. Kaolinite and sericite may form together (Fig 19), as is also shown by the calculated composition of many altered rocks. Wherever abundant carbonates form, metasomatically, together with sericite, kaolinite seems to be absent. It often occurs on cassiterite-veins (though it is possible that the kaolinite may here be simply a secondary alteration of topaz), further, together with sericite, in veins of the pyritic galena-formation of Freiberg, in some veins of propylitic character, as at Cripple Creek, and in veins where the action of stronger reagents, such as sulphuric acid, seems probable (Summit District, Colo.,* De Lamar, Idaho†). Kaolinite is formed most abundantly in the upper, oxidized zones of many ore-deposits.

Zeolites.—These hydrated minerals are almost completely absent from fissure-veins. Exceptions are the silver veins of Andreasberg in the Hartz, and Kongsberg in Norway, where many zeolites occur as vein-filling with quartz and calcite. As metasomatic minerals, they occur in the Lake Superior copper-veins replacing feldspars and other minerals. Daubrée has described zeolites forming in old bricks at Plombières, by the action of thermal waters ascending on a vein which does not contain any

* R. C. Hills, *Proc. Colorado Sci. Soc.*, vol. 1, pp. 20-36.

† W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, part iii., pp. 171, 172.

of these minerals W. H. Weed finds stilbite with quartz as the filling of a recent vein by ascending hot waters at Boulder, Montana. The absence of the zeolites from veins is somewhat difficult to explain, as it is well known that many of them may be formed at very widely differing pressures and temperatures. Very slight modifications of condition may result in the formation of hydrous or anhydrous minerals. Thus, for instance, Friedel and Sarasin^{*} found that when a solution of silicate of sodium mixed with silicate of aluminum, in proportions required to form albite, was heated to 500° C. in a closed tube, analcite was formed. When excess of the alkaline silicate was used, albite resulted.

Pyrite.—Of all the sulphides occurring as metasomatic minerals pyrite is naturally the most common. In most fissure-veins, it impregnates the adjoining rock in varying amounts, even if the alteration in other respects has not progressed far. The mineral has a remarkable tendency to crystallization when developing in the rock, as contrasted with its often massive texture when occurring as a filling of open spaces. The forms assumed are either cubes or pentagonal dodecahedrons, or a combination of both.

Pyrite develops in nearly every one of the ordinary constituents of rocks. By preference, it forms in the new aggregates of sericite, carbonates and chlorite so common in altered rocks, but it also occurs in the fresh original minerals of the rocks, as in quartz, feldspar, hornblende and pyroxene. It is also abundant in calcareous shales adjoining veins. It is common to find small, sharp crystals embedded, for instance, in perfectly clear quartz grains, which show no break in their optical orientation around the secondary crystal, proving that the genesis is by purely metasomatic processes, and not, as may be advocated in the case of crystallization in soft aggregates, by the mechanical pressure of the growing crystal. On the other hand, the development of a larger crystal in quartz or feldspar will often produce a breaking-up of the grains as an optical unity, and the substitution for it of an interlocking aggregate of smaller grains. To what force this is due is not certain; there are usually no indications of direct pressure from the growing crystal.

^{*} *Comptes rendus, Acad. des Sci.*, Paris, July, 1883, vol. xcvi, p. 291

The pyrite crystals are often bordered by a small rim of calcite or quartz; and little bunches of sericitic fibers may adhere to them, when forming in quartz. On the whole, the pyrite seems to obtain some, if not all, of its iron from the ferro-magnesian minerals, rather than from the magnetite and titaniferous ores, which appear to alter to carbonates and rutile.

Marcasite.—In metasomatic development, this mineral is rare, though it has been observed accompanied with kaolin, at De Lamar, Idaho, as the result of the hydrothermal alteration of rhyolite*. It is always crystallized, and the individuals combine to arborescent forms.

Chalcopyrite.—This mineral is not common in the metasomatic rocks of gold- and silver-veins, but it forms abundantly in certain replacement-veins, such as those of Butte, Mont., and Rossland, B. C. In such cases, it may replace any of the ordinary rock-forming minerals. It forms in irregular masses, is rarely crystallized, and is frequently accompanied by a narrow lining of chlorite.

Arsenopyrite.—Like pyrite, arsenopyrite nearly always forms in crystals, these show the simple combination of rhombic prisms and striated dome, and may also replace any of the rock-forming minerals. Next to pyrite it is the most common sulphide in the altered rocks adjoining veins.

Pyrrhotite.—This mineral is not abundant either in vein-filling or in metasomatic rocks. Indeed, in many classes of veins it is entirely absent; and if it happens to be present in the rock close to the vein, it may suffer alteration to pyrite under the influence of the vein-forming agencies.† As a product of replacement of feldspar and ferro-magnesian silicates, it occurs in the Rossland veins of British Columbia, associated with chalcopyrite. The conditions governing the formation of pyrrhotite are not fully known. It has been artificially reproduced, but not under conditions which seem analogous to those of nature. At any rate, the mineral can only be formed under very strongly reducing influences.

Galena.—By preference, galena replaces calcite and dolomite. Hence the great abundance of metasomatic galena-deposits in

* 20th Ann. Rept. U. S. Geol. Surv., part iii., p. 169.

† 17th Ann. Rept. U. S. Geol. Surv., part ii., p. 147.

limestone, calcareous shale and similar rocks. In crystalline igneous or metamorphic rocks, it is not abundant as a metasomatic product. But it may replace other minerals, especially quartz. Metasomatic galena scarcely ever appears in crystalline form, but often forms wiry, extremely irregular masses. Fig. 25 shows its appearance in primary quartz of a quartz-diorite. It only occurs in quartz which is completely filled with fluid inclusions, and its growth begins as little knots and particles, dotted over any given plane of fluid inclusions. These dots, of which some are shown in the figure, finally appear to have united to larger masses. The quartz grain in which the galena occurs is partly broken up into new quartz aggregates. Galena replacing quartz in quartzite from Northern Idaho is shown in Fig. 16. Gradually extending, the galena unites to larger masses, as illustrated in Fig. 17.

The replacement of calcite by galena is illustrated by Fig. 29, representing part of a section from the Elkhorn mine, Montana, which Mr. W. H. Weed kindly put at my disposal. The rock, a crystalline limestone, apparently free from organic matter, contains small, partly idiomorphic quartz grains, scattered among the larger grains, and also many small veinlets of secondary quartz. There is thus at least an incipient silicification accompanying the formation of the galena. In the little quartz veins and throughout the rock are small, sharply defined pentagonal dodecahedrons of pyrite, nearly always connected with small quartz grains. The galena appears in several smaller grains closely intergrown with pyrite; also in larger masses surrounded by a narrow rim of pyrite, and by clusters of small secondary grains and crystals of quartz. The galena is not clearly crystallized, but appears in small, solid masses, developing along the cleavage planes of calcite so that rhombohedral grains of the latter may be almost surrounded by galena.

Concerning the chemical reactions involved in the replacement by galena opinions differ. Some think that the slightly soluble sulphate of lead is reduced from solutions by organic matter—and adduce as confirmation the universal occurrence of galena in limestone or other sedimentary rocks, presumably containing organic matter. Another view is that, the sulphide of lead being soluble to a considerable extent in water containing sodic sulphide (Doelter), a simple precipitation from solu-

tion has taken place, dependent on the simultaneous solution of limestone and separation of silica

For most cases I would be inclined to the latter view, since the small quantity of organic matter available, for instance in the Elkhorn limestone or in the Cœur d'Alene quartzite, seems utterly insufficient to reduce such large masses of galena as are found at these localities. Besides, silver-lead veins may occur in the same districts in very different rocks. Thus, for instance, in the Wood River region, Idaho, they are found not only in the limestone but also in granite, which certainly does not contain organic substances

In this connection should be mentioned the replacement of rhodonite by galena and zinc-blende, described and figured from Broken Hill, Australia, by Prof R. Beck. From the same locality Mr Jaquet described and figured galena replacing orthoclase, and a silver mineral, probably argentite, replacing garnet, and perhaps quartz, in a garnet schist

Zinc-blende and Other Sulphides—In metasomatic occurrence zinc-blende is extremely similar to galena. It is usually found as irregular grains, replacing limestone, quartzite (Fig. 17), and many minerals in igneous rocks.

Much additional material might be quoted regarding the replacement of rocks by other sulphides; the literature on the subject should be used, however, with care, since critical studies of the modes of replacement are very few, and some statements are simply based on casual inspection with the naked eye.

Many other sulphides are undoubtedly formed by metasomatic replacement. Enargite, for instance, is noted by Emmons* as replacement thus present in the altered vein-rock of Butte, Mont.

Tellurides—Tellurides of gold and silver are found at Cripple Creek and elsewhere, under circumstances indicating metasomatic deposition.

Native Copper.—This metal replaces many minerals. According to Pumpelly,† it replaces feldspar and various zeolites in the Lake Superior amygdaloids; and most of the large masses of copper there found are believed to be metasomatic.

* *U. S. Geol. Surv.*, Folio 38

† *Geol. Surv. Mich.*, vol. 1, part ii., p. 19, *et seq.*

Gold and Silver.—Native gold and silver are likewise important results of replacement in many veins. It is well known that masses of these metals are occasionally found in the country-rock away from the fissure, and these occurrences are probably to be interpreted as metasomatic, though the process has not been followed in its details.

Gold is also often contained in the replacing pyrite and other sulphides, and free gold can be obtained by panning from certain kinds of altered vein-rock. But caution should always be observed in stating such observations. I have known instances of supposed replacement where, in fact, all the value was derived from the filling of minute fissures and cracks.

Resistant Minerals.

Among the minerals which yield not at all or only with difficulty to metasomatic influences are apatite, muscovite, zircon and chromite. The resistance of apatite is very remarkable; for according to R. Muller* apatite is soluble with comparative ease in water containing carbon-dioxide.

PART III

THE FISSURE-VEINS CLASSIFIED ACCORDING TO METASOMATIC PROCESSES

Under this head, I suggest fourteen classes of fissure-veins, each usually characterized by its own distinctive metasomatic process. These fourteen divisions are not offered as a permanent classification, though most of them are sharply defined. The principle is not unqualifiedly good for a genetic classification, for the reason that the same waters may cause a different metasomatic development in different rocks.

The list, in each title of which the first word indicates the predominant metasomatic mineral or process, is as follows: 1. Topaz-cassiterite veins; 2. Scapolite-apatite veins, 3. Tourmalinic gold-copper veins, 4. Biotitic gold-copper veins, 5. Propylitic gold- and silver-veins; 6. Fluoritic gold-tellurium veins, 7. Sericitic and kaolinic gold- and silver-veins, 8. Sericitic and calcitic gold- and silver-veins, 9. Siliceic and calcitic quicksilver-veins; 10. Sericitic copper-silver veins; 11. Siliceic

* *Tsch. Min. Mitt.*, p. 25, 1877

and dolomitic silver-lead veins, 12 Sideritic silver-lead veins; 13 Sericitic silver-lead veins; 14. Zeolitic copper- and silver-veins.

1 *Topaz-Cassiterite Veins.*

This sharply defined class is characterized by exceedingly strong metasomatic action, with fluorine as mineralizing agent, resulting in often coarse-grained, altered rocks, containing topaz and sometimes tourmaline, besides an often considerable percentage of cassiterite.

The cassiterite-veins are characterized by their occurrence in connection with intrusive igneous rocks, and by the pneumatolytic change of the country-rock to *greisen*, a granular rock consisting chiefly of quartz, topaz and white mica, usually containing fluor and lithia. Tourmaline and cassiterite are usually accessory constituents of this rock. The feldspar and the brown mica of the original rock are destroyed, and the minerals mentioned above are added. Topaz often forms pseudomorphs after quartz, cassiterite, tourmaline and topaz, after feldspar. The alteration of the country-rock varies somewhat in chemical aspects, but is distinguished by strongly marked transportation of substance.

In the granular greisen, the new minerals appear as individuals of considerable extent and optical continuity, perhaps indicating that the processes by which it was formed were more active and energetic than those producing the aggregate structure commonly found in altered vein-rocks. The minerals found in the metasomatic wall-rock appear also in the fissures themselves; hence the same chemical process must have been active in both. Other rocks, such as gneiss, quartz-porphyrty and rhyolite, show similar alteration, though tin-deposits do not so commonly occur in them. A notable feature of the cassiterite-veins is the occurrence of apatite, a mineral generally unknown in fissure-veins. Under ordinary circumstances, in altered vein-rocks, apatite is the last mineral to remain fresh, after all other primary minerals have been destroyed.

Vogt's explanation* of the genesis of cassiterite-veins and the alteration of their wall-rocks follows closely the previously expressed views of Elie de Beaumont, Daubrée, Le Neve Fos-

* J H L Vogt, *Zeitschrift f. prakt. Geologie*, 1895, p. 145.

ter and Dalmer. He assumes that they were formed immediately after, or even during, the granitic eruptions, and, further, that the mineral solutions originated by the action of hydrofluoric acid and hydrochloric acid on the magma, still entirely or partly in igneous fusion. By means of these, fluorides of silicon, tin, boron and lithium were extracted, as well as phosphoric acid. These solutions took place under pneumatolytic conditions, that is, the "critical point"* had been passed and the substances were present in a gaseous state in spite of the high pressure. These extracts in gaseous state ascended on the previously formed fissures and strongly attacked the adjoining country-rock, changing it to greisen by means of replacement by minerals containing fluorine and other mineralizing agents. Different rocks were, perhaps, not affected exactly in the same way. For instance, the altered product resulting from schists is not quite similar to that resulting from granite, this being possibly due to the fact that the schists were not heated to such a degree as was the granite. While the formation of the greisen took place after the consolidation of the rock, as is evidenced by the fact that fissures could form in it, still it is believed that the temperature must have been very high, and, in fact, that the lower masses of the granite were not yet consolidated.

Altenberg and Zinnwald, Saxony.—The tin-deposits of Altenberg and Zinnwald, in Saxony, have been lately investigated by K. Dalmer.† The cassiterite-deposits of Altenberg consist, as is well known, of a number of ore-fissures which sometimes carry a notable amount of quartz, mica and topaz, as well as cassiterite. Over a considerable area traversed by these veinlets appears a greisen, locally called *zwitter*, which Mr. Dalmer shows to have resulted unquestionably from the metasomatic alteration of the granite. The process consisted of a replacement of feldspar, principally orthoclase, by topaz containing lithium and fluorine. The beginning of the process is often

* The critical temperature for water is $+365^{\circ}\text{C}$ at a pressure of 200 atmospheres. For most other substances the critical point is passed below this temperature and pressure. It is, perhaps, not needless to state that the passing of the critical temperature does not mean that the substances are dissociated.

† *Erläuterungen zur Geologischen Spezialkarte des Königreichs Sachsen, Section "Altenberg-Zinnwald,"* Leipzig, 1890.

visible, small strings of aggregates of mica and topaz pervading the feldspar. These strings repeatedly cross each other, and by extension of the mineral individuals complete replacement is attained. The greisen consists of quartz, 50.28, topaz, 12.14, mica, 36.80, and cassiterite, 0.43, total, 99.65 per cent.

Dr. Dalmer has calculated the composition of the rock from these percentages, and obtained a result which closely agrees with the old analysis of the same rock by Rube, quoted in Cotta's *Gangstudien*. The following table shows the result, I being the fresh granite and II the altered product.

	I	II
	Per Cent	Per Cent
SiO ₂	74.68	70.41
TiO ₂	0.71	0.49
SnO ₂	0.09	0.49 [*]
Al ₂ O ₃	12.73	14.86
Fe ₂ O ₃		1.42
FeO	3.00	5.09
CuO	0.50	..
MnO	..	0.20
CaO	0.09	0.21
MgO	0.35	0.09
K ₂ O	4.64	3.01
Na ₂ O + Li ₂ O	1.54	0.98
Fl		3.10
H ₂ O	1.17	..
	<hr/> 99.50	<hr/> 100.44

From these two analyses it is clear that the formation of greisen does not by any means involve silicification. Dalmer concludes that the principal changes consisted in the addition of FeO, Fl, SnO₂, and possibly Al₂O₃, while K₂O, Na₂O and SiO₂ have been subtracted. In the absence of further knowledge of the relations of volume during the alteration, it is scarcely possible to conclude from the comparison of these analyses alone what the actual changes have been. The determination of specific gravities of the rocks would probably help to obtain a clearer insight in regard to this matter. This much is evident, that the mineral aggregate of the granite has changed to a new aggregate of greater density.

It will be observed that the second analysis contains no water. This has probably been unintentionally omitted, as it must

* As cassiterite, 0.43, in mica, chemically combined, 0.06.

surely be present, being contained, chemically combined, both in topaz and in the lithium-mica.

In view of the fact that in this alteration not only the potassium-aluminum silicate, muscovite, but also the pure aluminum fluo-silicate or topaz appears, it is interesting to note that metasomatic kaolin is undoubtedly present in cassiterite-veins. Pseudomorphs of it after topaz have been frequently observed, and it is often stated that "steinmark" is present in the veins, this being really only a synonym for kaolin. Daubrée long ago called attention to the connection of kaolin with cassiterite-veins.

In several places the alteration of the granite and the adjoining porphyry is of a radically different character, and consists in a complete silicification. While this is not the normal process, yet it appears fairly common, and must be taken into consideration in attempting to explain the genesis of these veins.

Mt. Bischoff, Tasmania. The rocks of the tin-deposits of Mt. Bischoff, in Tasmania, have lately been described by W. von Fircks,⁺ who devotes considerable space to the alteration which they have suffered. The tin-deposits appear in an area of quartzites and clay-slates with dikes of quartz-porphyry. Granite is present some distance from the mines. The deposits are in part fissure-veins carrying cassiterite, pyrite, arsenopyrite, fluorite, wolframite, tourmaline and siderite. The latter mineral is notable, because not usually present in veins of this character. Another part of the deposits is formed by replacement, chiefly of porphyry dikes. All rocks in the vicinity of the mines are much altered. The schists and slates contain much tourmaline, and are in part changed to typical *tourmalin-fels* by complete replacement, only a few grains of the original rock remaining. Besides the tourmaline, some siderite also appears, while topaz is present in but small quantity. These altered schists contain cassiterite (rare), and also pyrite, arsenopyrite, pyrrhotite, fluorite, calcite, siderite and pyrophyllite as metasomatic products. The tourmalinization begins with the appearance of needles and bunches of crystals of tourmaline traversing fresh quartz grains, as shown in Fig. 23. These tourmaline crystals, by further growth, finally replace the

* *Zeitschr. d. d. geol. Ges.*, Bd 11, p. 433, 1899

quartz altogether. According to the description, the fissure-veins must have been produced partly, at least, by processes of filling. Where they traverse the schists, their walls show impregnation of ores and the development of a great quantity of sericite. Sometimes, it should be added, the wall-rocks are completely silicified. Of greatest interest are the quartz-porphry dikes and their alteration-products. The principal secondary mineral in these dikes is topaz, while tourmaline is only of subordinate importance. The groundmass of the porphyry is changed to aggregates of topaz and quartz. The quartz phenocrysts are usually intact, while the feldspars are often completely replaced with cassiterite, pyrite, pyrrhotite, arsenopyrite and fluorite, as shown in Fig. 22. In the final product, the feldspar and mica have disappeared completely, the zircon being, besides quartz, the only mineral which has withstood the metasomatic influences. Here again siderite appears occasionally, seemingly of simultaneous formation with the other metasomatic constituents. There is, as shown by the author, a great similarity between the metasomatic action in these deposits and that described from the vicinity of Schneckenstein, in Saxony, by Mr. M. Schroeder.¹

None of the rocks from Tasmania can well be designated as "greisen"—a name which ought to be reserved for the granular alteration-products of granite consisting of quartz, lithion-mica, topaz and cassiterite. Here again, as at Altenberg, we find occasionally, seemingly as an exception, a change in the metasomatic processes resulting in complete silicification of the wall-rock.

Prof. R. Beck† has discussed the tin-ore deposits from Banca and Billiton, in referring to the work of Mr. Verbeek on the same subject. It has been shown by Prof. Cl. Winkler that many granites and rocks allied to *hornfels* contain a small amount (from 0.01 to 0.07 per cent) of oxide of tin. This is not cassiterite, but appears to be chemically combined with silicates, partially replacing SiO_2 . Sandberger had, indeed, also shown long ago the presence of tin in certain muscovites from different places in Europe. Another very interesting fact shown by Mr.

¹ *Erläut. z. Geol. Sp. Karte des Königr. Sachsen*, Leipzig, 1885, Section "Schneckenstein."

† *Zeitschr. f. prakt. Geologie*, 1898, p. 121.

Verbeek is a stanniferous siliceous sinter, deposited at a hot spring in Malacca. This sinter contains, according to an analysis by St. Meunier, SiO_2 , 91.8, SnO_2 , 0.5, Fe_2O_3 , 0.2, and H_2O , 7.5 per cent.

This observation possesses the greatest importance for our knowledge of tin-deposits, as it shows that the metal may be held in solution and deposited at ordinary pressure by thermal waters. Prof. Beck shows the presence of primary cassiterite in some granites from the same locality, and also points out that the veins are practically identical with tin-deposits from other parts of the world, being characterized by an often strong alteration of the adjoining country-rock, converting it into typical greisen. The feldspar is replaced by topaz, cassiterite and muscovite. The typical greisen is illustrated in Fig. 24, copied from Prof. Beck's article.

2 *Scapolite-Apatite Veins*

This interesting group of veins has lately been described in detail by Prof. Vogt*. It is characterized by some most remarkable features, closely relating it on one hand to the group of the cassiterite-veins, but showing, on the other hand, strong relationships with the pegmatite-veins, formed under pneumatolytic conditions and exceedingly high temperature and pressure. The structural features of scapolite-apatite veins are not those of fissure-veins, as they chiefly follow contraction-joints (in gabbro). Indeed, this may be said to some extent of cassiterite-veins; but the latter often also follow strong, well-defined fissures. At any rate, it seems probable that the apatite-veins were formed almost simultaneously with, or very closely following, the solidification of the magma.

The characteristic minerals are apatite, phosphates, rutile, pyrrhotite, specularite, enstatite, scapolite, hornblende and malacolite, many of which are absolutely foreign to ordinary fissure-veins. A most characteristic feature is the presence of chlorine (in apatite and scapolite), just as fluorine persistently appears in cassiterite-veins. In the gabbro adjoining the vein-filling, the labradorite is usually altered to scapolite, and the diagenesis to hornblende. This alteration is explained (*loc. cit.*, p. 456) as a saturation of the country-rock under high pressure.

* J. H. L. Vogt, *Zeitschr. f. prakt. Geol.*, 1895, p. 367

by the sodium chloride which acted as a mineralizing agent during the formation of the veins.

3. *Tourmaline Gold-Copper Veins.*

In the type of veins distinguished by a gangue of tourmaline and quartz the country-rock is generally subject to strong metasomatic changes. The vein-forming agents, which contained boron and some fluorine, appear to have attacked the adjoining rock strongly, and caused a more or less complete metasomatic conversion into tourmaline. Von Groddeck^{*} has described an occurrence of this kind from Tanaia, Chile, in which veins containing copper-ores cut gabbro and porphyrites. The tourmaline is here not only present in the filling of the fissure but is also distributed through the adjoining country-rock. A further contribution to the knowledge of veins carrying tourmaline was given by A. W. Stelzner[†] in his description of occurrences of this kind from Chile. The rocks examined, from the mining district of Las Condes, 90 miles east of Santiago, consist of granite and greenish porphyritic rocks, which the author is inclined to consider as altered andesites. The vein-filling is pyrite, chalcopyrite, quartz and a loose porous mass of tourmaline needles. By a specific-gravity separation of the latter, Stelzner obtained, as a residue, zircon in well-developed crystals, as well as specularite and anatase. The zircon is probably developed under the influence of the vein-forming solutions, the anatase and specularite quite certainly so. Again the fact is emphasized that the adjoining country-rock is bleached and filled with pyrite and tourmaline.

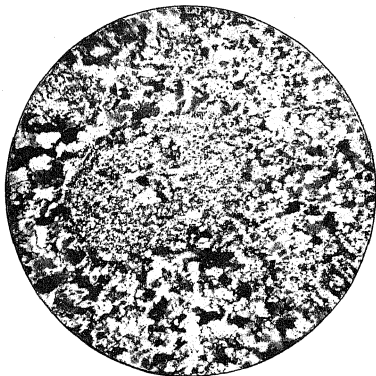
Dr. E. Hussak[‡] has recently described the auriferous quartz-vein of Passagem, in Minas Geraes, Brazil. This vein, which lies, parallel to the stratification, between mica schist and itabirite (hematite-mica-schist), shows a filling of quartz, tourmaline, and arsenopyrite, with smaller quantities of pyrite and pyrrhotite. The arsenopyrite is strongly auriferous. A very interesting feature is the occurrence of zircon and monazite in the ore, formed apparently simultaneously with it. Here, too, the tourmaline is present in the adjoining country-rock. Musco-

* *Zeitschr. d. d. geol. Ges.*, 39, 1887, p. 237.

† Posthumously published in *Zeitschr. f. prakt. Geologie*, 1897, p. 41.

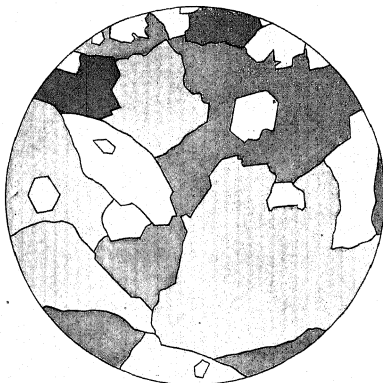
‡ *Zeitschr. f. prakt. Geologie*, 1898, p. 345.

FIG. 1.



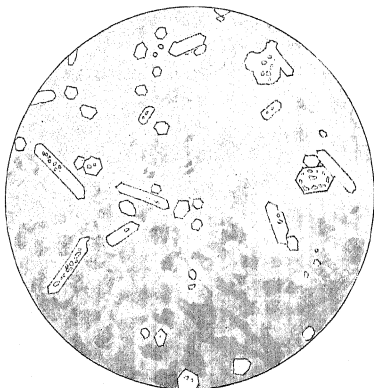
Silicified Calcareous Shale with Outline of Foraminiferal Test. Diadem lode, Plumas county, Cal. (After H. W. Turner.) Crossed nicols. All quartz. Magnified 29 diameters.

FIG. 2.



Primary Vein Quartz from Filling. Federal Loan mine, Nevada county, Cal. Crossed nicols. All Quartz. Magnified 14 diameters.

FIG. 3.



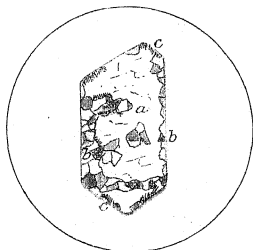
Incipient Silicification of Limestone. Aspen, Colo. White areas represent quartz crystals with small inclusions of limestone. Magnified 30 diameters.

FIG. 4.



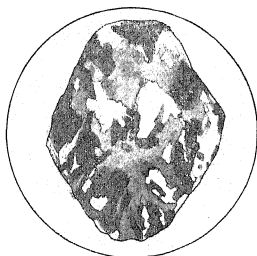
Silicified Limestone ("Jasperoid"). Aspen, Colo. Crossed nicols. All quartz. Small inclusions of calcite in some of the grains. Magnified 30 diameters.

FIG. 5.



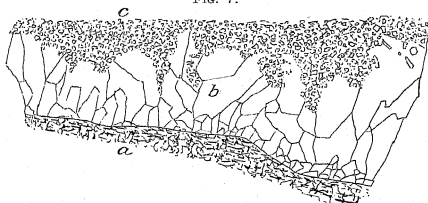
Incipient Silicification of Orthoclase Crystal in Rhyolite. Silver City, Idaho. Crossed nicols. *a*, Orthoclase; *b*, secondary quartz; *c*, sericite. Magnified 34 diameters.

FIG. 6.



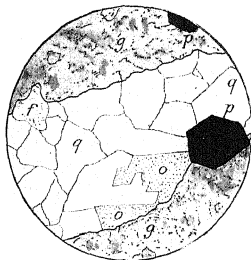
Hornblende Crystal with Partial Chloritization and Silicification; in Propylitic Andesite. Virginia City, Nevada. (After G. F. Becker.) White, quartz and calcite; grey, chlorite; dark grey, hornblende. Magnified 70 diameters.

FIG. 7.



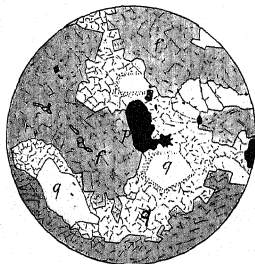
Veinlet of Quartz (*b*) on Chloritized Basalt (*a*), Replacing Silicified Rhyolite (*c*). Bishop vein, Silver City, Idaho. Magnified 11 diameters.

FIG. 8.



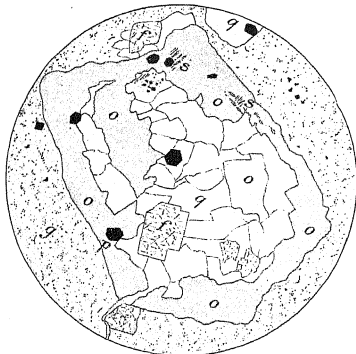
Filled Veinlet in Andesite Breccia. Independence mine, Cripple Creek, Colo. *q*, Quartz; *o*, valencianite (orthoclase); *p*, pyrite; *f*, fluorite; *g*, ground-mass of breccia. Fluorite and pyrite partly replacing ground-mass. Magnified 11 diameters.

FIG. 9.



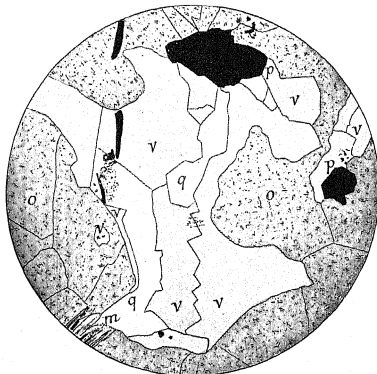
Fluorite Ore, Replacing Phonolite. Portland mine, Cripple Creek, Colo. *p*, Pyrite; *q*, quartz, coarser and finer grains; *f*, fluorite. Magnified 50 diameters.

FIG. 10.



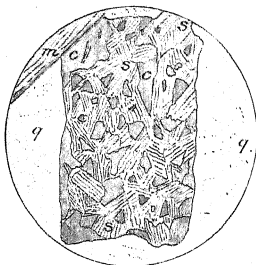
Orthoclase Grain (*o*) in Granite Andesite Breccia, Partly Replaced by Quartz (*q*); Fluorite (*f*); Pyrite (*p*); Sericite (*s*); Ground-Mass of Breccia (*g*). Independence mine, Cripple Creek, Colo. Magnified 60 diameters.

FIG. 11.



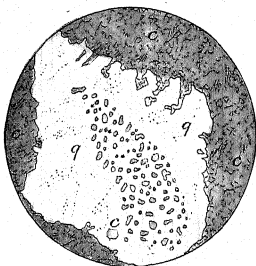
Filled Space of Dissolution in Granite. "Granite Ore," Independence mine, Cripple Creek, Colo. *o*, Orthoclase of granite; *m*, biotite, converted into valencianite and pyrite; *v*, valencianite (secondary orthoclase), showing crustification; *q*, quartz. Magnified 20 diameters.

FIG. 12.



Andesine Crystal in Granodiorite, Replaced by Sericite and Calcite. Pinefree vein, Ophir, Placer county, Cal. *q*, Quartz; *m*, muscovite; *c*, calcite; *s*, sericite. Magnified 80 diameters.

FIG. 13.



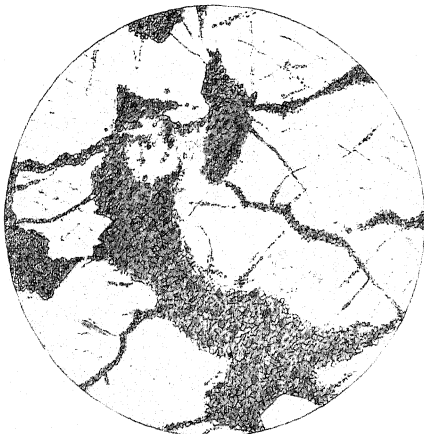
Quartz Grain in Same Section, Partly Replaced by Calcite. *q*, Quartz; *c*, calcite with some sericite replacing from outside; also, secondary calcite grains forming on inclined fissure-plane in quartz. Magnified 80 diameters.

FIG. 14.



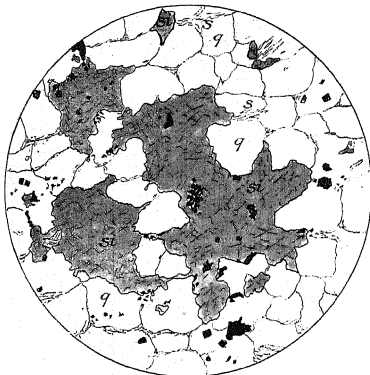
Fluorite Replacing Limestone. Florence mine, Judith Mountains, Mont. *f*, Fluorite; *l*, limestone; *q*, secondary quartz. Magnified 7 diameters.

FIG. 15.



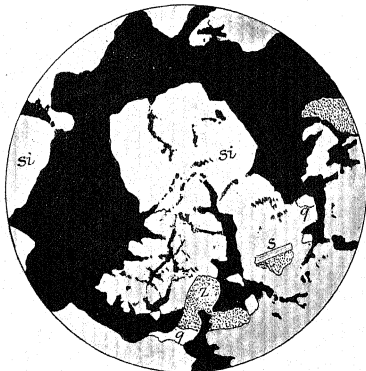
Metasomatic Replacement of Quartz in Granodiorite by Calcite and Sericite. Providence mine, Nevada City, Cal. White areas quartz. Shaded areas fine-grained calcite with some sericite. Magnified 52 diameters.

FIG. 16.



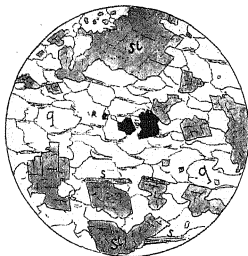
Siderite with Pyrite and Galena, Replacing Quartzite. Helena and Frisco mine, Cœur d'Alene, Idaho. *q*, Quartz grains; *s*, sericite; *si*, siderite; black, galena and pyrite. Magnified 100 diameters.

FIG. 17.



Replaced Quartzite, Same Locality as Fig. 16. Black, galena; *z*, zinc-blende; *q*, quartz; *s*, sericite; *si*, granular siderite. Quartzite in same section gradually changing to this ore. Magnified 35 diameters.

FIG. 18.



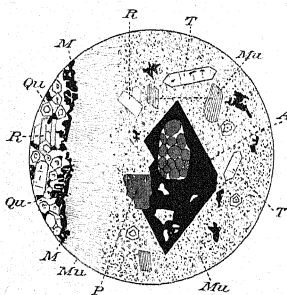
Quartzite Partly Replaced by Siderite and Pyrite. Helena and Frisco mine, Cœur d'Alene, Idaho. *q*, Quartz grains; *s*, sericite; *st*, siderite with partly rhombohedral form; black, pyrite. Magnified 100 diameters.

FIG. 19.



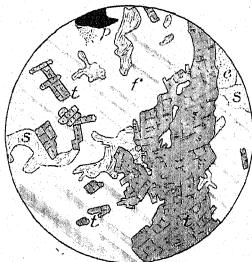
Orthoclase Partially Replaced by Muscovite and Kaolinite. From quartz-monzonite adjoining recent vein, Boulder, Mont. *o*, Orthoclase; *q*, quartz; *m*, muscovite; *k*, kaolinite. Magnified 22 diameters.

FIG. 20.



Part of Andalusite Crystal Altered into Muscovite, Arsenopyrite, etc. Passagem gold-quartz vein, Brazil. (After E. Hussak.) *M*, Pyrrhotite; *A*, arsenopyrite; *P*, pyrite; *Qu*, quartz; *R*, rutile; *Mu*, muscovite; *T*, tourmaline.

FIG. 21.



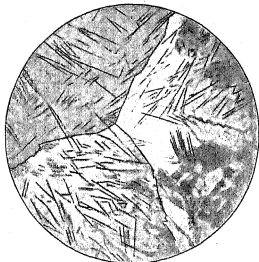
Replacement-Veinlet of Tourmaline in Fresh Andesine Grain. Keystone mine, Meadow Lake, Nevada county, Cal. *t*, Tourmaline; *f*, andesine; *e*, epidote; *s*, sericite. Magnified 50 diameters.

FIG. 22.



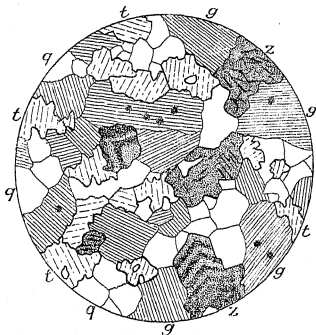
Feldspar Crystal Replaced by Topaz, Quartz, Fluorite and Cassiterite, in Ground-Mass Converted to Partly Radial Aggregates of Topaz. Mount Bischoff, Tasmania. (After W. von Fireks.)

FIG. 23.



Incipient Tourmalinization of Quartzite. Three quartz grains shown. Needles single and in bunches, of tourmaline. Mount Bischoff, Tasmania. (After W. von Fireks.)

FIG. 24.



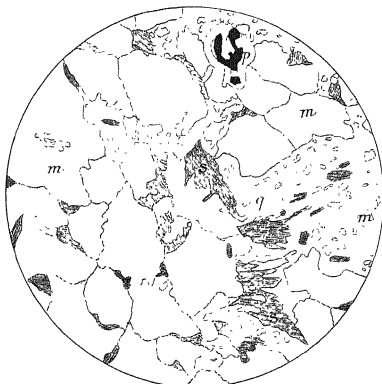
"Greisen" from Tin-Deposits of Banca, Malay Peninsula. Derived from granite. (After R. Beck.) *g*, Lithion-mica; *q*, quartz; *z*, cassiterite; *t*, topaz. Stippled spots in mica consist of zircons and rutiles, surrounded by polychroic ring. Slightly magnified.

FIG. 25.



Altered Quartz-Mica-Diorite. Croesus mine, Wood River, Idaho. *a*, Galena; *b*, arsenopyrite; *c*, chalcopyrite; *d*, sericite; *e*, quartz with secondary fluid inclusions; *f*, rutile; *g*, chlorite. Magnified $19\frac{1}{2}$ diameters.

FIG. 26.



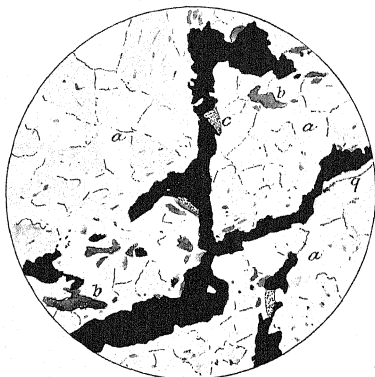
Altered Serpentine. Idaho mine, Grass Valley, Cal. *m*, Magnesite; *s*, serpentine; *p*, pyrite; *q*, fine granular quartz. Magnified 15 diameters.

FIG. 27.



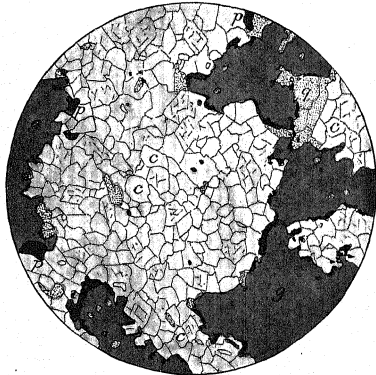
Altered Granodiorite. Bellefontaine mine, Nevada City, Cal. *m*, Fine aggregate of sericite, with a little calcite and secondary quartz, replacing orthoclase and andesine; *b*, original biotite altered to sericite; *q*, original quartz; black, pyrite with included sericite. Magnified 15 diameters.

FIG. 28.



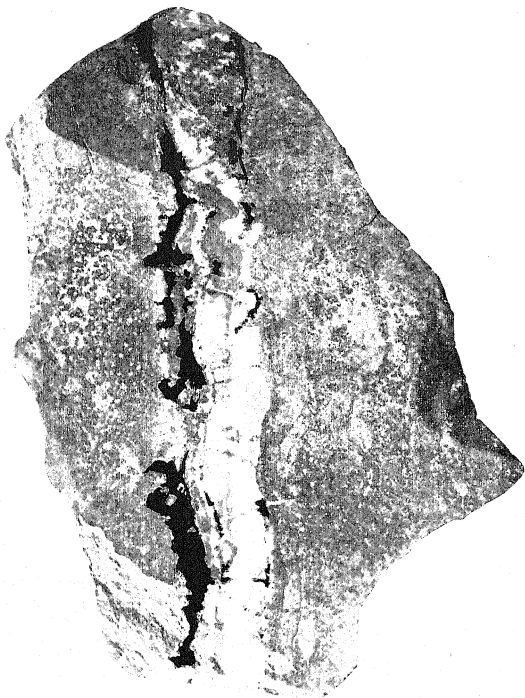
Replacement-Vein in Syenite Rock. War Eagle mine, Rossland, British Columbia. *a*, Granular aggregate of orthoclase with very little sericite; black, secondary pyrrhotite; *b*, secondary biotite; *q*, secondary quartz; *c*, chlorite. Magnified 60 diameters.

FIG. 29.



Galena, Replacing Crystalline Limestone. Elkhorn mine, Montana. *g*, Galena; *p*, pyrite; *c*, calcite grains of limestone; *q*, secondary quartz. Magnified 15 diameters.

FIG. 30.



Quartzite Showing Filled Quartz Veinlet and Accompanying Galena, Replacing the Quartzite on One Side of the Filled Fissure. The quartzite contains some replacing siderite. Bunker Hill and Sullivan mine, Cœur d'Alene, Idaho. Black, galena; white, quartz; grey, quartzite. Natural size. Reproduced from photograph.

vite or sericite is also described as very plentiful in the schistose rock adjoining the vein. Certain crystals of andalusite, occurring (as inclusions?) in the vein, are completely altered into sericite, rutile, arsenopyrite and pyrite, as is well shown in Fig. 20 (reproduced from Dr. Hussak's paper). The author concludes from his study that the deposit is a product of igneous injection, and should be considered a dike rather than a fissure-vein, basing this conclusion largely on the occurrence of zircon, monazite, tourmaline and staurolite in the adjoining rock. It is a question whether this argument will carry conviction. From Dr. Hussak's excellent descriptions I should be inclined to consider this interesting occurrence as a fissure-vein deposited by aqueous agencies, though, perhaps, at a higher temperature than ordinary veins. The contact-minerals cited by the author do not appear to be confined to the adjoining rock, but are present in the whole series of schists. The very schistose and sericitic quartzite forming the wall of the vein, and the presence of pseudomorphic sericite after andalusite, as well as the apparently simultaneous forming of arsenopyrite and sericite, appear to me evidence that the deposit of Passagem is really a normal vein. The tourmaline is here also present in the country-rock, apparently replacing it to a greater or lesser degree.

Again, similar deposits have been described from Meadow Lake, Nevada county, Cal.,* where granitic and dioritic rocks contain fissure-veins with pyrite, arsenopyrite, pyrrhotite, zinc-blende, and various secondary copper-ores, indicating primary chalcopyrite in a gangue of quartz and tourmaline, with which some yellow epidote is usually associated. Chlorite is also common in the gangue as well as a brown mica, probably biotite. A colorless mica and a little calcite were also observed. In contrast to the usually clearly defined fissure-veins of the gold-belt of California, in which the quartz-filling is the predominant ore, these veins show very irregular and undefined walls, and it is clear that the mineral-forming solutions rose along very narrow fissures, from which they penetrated more or less deeply into the adjoining country-rock, and there, by metasomatic replacement deposited the auriferous ores. One of these occurrences

* Waldemar Lindgren, *Am. Jour. of Sci.*, 3d series, vol. xlv1, Sept., 1893, p. 201

is illustrated in Fig. 21. The specimen is from the Keystone mine, and shows a granitic rock traversed by a narrow fissure, from which an intense alteration has proceeded, converting the immediate rock into an aggregate of quartz and tourmaline. The metasomatic process is well shown in the figure.

Prof. Vogt describes¹ certain veins in Telemarken, Norway, which he considers as related to the cassiterite-veins proper. These contain chalcopyrite, bornite, and chalcocite, also a little native silver and gold, all associated with a gangue of fluorite, tourmaline, apatite, muscovite and calcite. They are considered to be genetically connected with the granite in which they appear, and the presence of tourmaline and apatite certainly suggests their close relationship to normal cassiterite-veins. The country-rock is a normal biotite-granite, with orthoclase, microcline and oligoclase, and no muscovite. The alteration extends for several feet on both sides of the veins, and all transitions are plainly visible. The first part of the process consists in a periphere change of biotite to muscovite and a little epidote; then the feldspars are attacked, muscovite and quartz together with a little calcite forming on the cleavage-planes; and finally the feldspars and biotite are entirely decomposed. The result is muscovite, quartz, calcite, rutile, zircon and apatite,—the latter two not altered, but constituting the only material remaining fresh from the unaltered rock. A little fluorite, chalcopyrite or bornite is also occasionally present in the product of alteration. Regarded from a chemical standpoint the process is not always the same. Sometimes, according to Vogt, substance is added; sometimes taken away. Quartz may occasionally prevail; at other places muscovite predominates. Prof. Vogt calls this altered rock a greisen; but the process of alteration as described by him is so nearly that of ordinary sericitic replacement that it may be questionable whether it would not be better to reserve the term greisen for the characteristic rock accompanying the cassiterite-veins. The process of formation in the case of the Telemarken veins was probably not carried on under the extreme conditions attending the normal cassiterite-veins.

The three classes of veins described above are undoubtedly

¹ *Zeitsch. f. prakt. Geol.*, 1895, p. 147

closely related and form a group, which, however, is connected by transitions from the following classes. In their whole development a distinct genetic connection with intrusive rocks is recognizable, and they seem to have been formed under exceptionally high pressure and temperature—in fact, partly under pneumatolytic conditions. The metasomatic action on the country-rock is very strong, and the presence of fluorine, chlorine or boron is characteristic. It is well to emphasize, however, that fluorine and boron appear in many other veins which certainly have not originated under pneumatolytic conditions, or even under high temperature or pressure. The three foregoing classes appear to form a transition from pegmatite-veins to ordinary-fissure veins.

4. *Biotitic Gold-Copper Veins.*

This class, of which few representatives are thus far known, are exemplified in the veins of Rossland, British Columbia. They are well-marked fissure-veins, contained in granular, intrusive rocks of great variety, ranging from diorites to monzonites and even syenites. The ore-minerals are pyrrhotite, chalcopyrite and a little arsenopyrite, all containing gold, but usually not in a free state, amenable to amalgamation, the principal gangue-mineral is biotite, with a little quartz, calcite, muscovite, amphibole, chlorite, tourmaline and garnet.

The veins are excellent examples of replacement-deposits, as there is but little material which can be identified as the filling of open cavities, while most of the ore has been formed by replacement of the rock-forming minerals on both sides of narrow fissures. The original hornblende of the rock is altered to aggregates of biotite foils, which also invade the feldspars, and simultaneously the feldspar substance is replaced from small cracks by pyrrhotite and chalcopyrite, forming a characteristic network which, by gradual extension, finally replaces the whole rock. One of these replacement-veinlets is illustrated in Fig 28. The sulphides do not as a whole have crystalline outlines, though in some places the grains show crystal-faces. The secondary character of the sulphides is further shown by narrow linings of quartz, chlorite or biotite. The feldspar substance, generally clouded by interpositions of biotite, muscovite, etc., usually presents a narrow, clear rim adjoining the sulphides. Exten-

sive biotitization results in fine-grained siliceous rocks, consisting of brown mica and quartz, possibly also secondary feldspars. Green secondary amphibole was noted in places, embedded in calcite. The whole process is more characteristic of dynamic metamorphism than of ordinary fissure-veins, and it is probable that the veins were formed under actual unrelaxing compression. Strongly reducing conditions are indicated (otherwise pyrrhotite would not form so exclusively), and the absence of notable quantities of carbon-dioxide. Along secondary slips, below the water-level, the pyrrhotite may be transformed to pyrite. Epidote appears to be absent. The veins are earlier than an extensive system of lamprophyric dikes which cut across them. These dikes were no doubt closely connected with the principal intrusion of igneous rock, and the conclusion may be drawn that the mineralization followed pretty closely upon the consolidation of the rock.

5. *Propylitic Gold- and Silver-Veins.*

General Features.—As the cassiterite-veins are closely connected genetically with certain intrusive rocks, so another group of veins shows a dependence on tertiary effusive rocks, such as andesites, dacites and basalts, in part also rhyolites and trachytes. In the vicinity of these veins there is a very extensive metasomatic action resulting in so-called propylite (named by v. Richthofen) which was regarded formerly as a primary rock-type, just as greisen has sometimes been regarded as a primary rock forming a variety of granite. But all fissure-veins in tertiary effusive rocks do not belong to this class, a considerable number belong under the head of sericitic veins. Rosenbusch expresses the process in the following apt words:*

“The characteristic features of the propylitic *faunes* consists in the loss of the glassy habit of the feldspars, in the chloritic alteration of the hornblende, biotite and pyroxene (often with an intermediate stage of uraltite), with simultaneous development of epidote, further, in alteration of the normal ground-mass into holocrystalline granular aggregates of feldspar, quartz, chlorite, epidote and calcite, and in a considerable development of sulphides” [usually pyrite] †

* *Elemente der Gesteinslehre*, Stuttgart, 1898, p. 303

† Rosenbusch adds (*loc. cit.* and *Minr. Phys. d. Mass. Gest.*, Stuttgart, 1896, p. 91) that similar rocks (excepting the pyrite) may result from atmospheric weathering. Against this statement I would protest, referring to page 586 of this paper.

Chemically, the change is not considerable; the principal additions consist of water and sulphur; some substance is often subtracted, usually lime or magnesia, while the alkalies show slight change. The following analysis, taken from Mr. Clarence King's monograph on the Comstock Lode, shows the composition of a propylitic andesite

	Per cent
SiO ₂ ,	64 62
Al ₂ O ₃ ,	11 70
FeO,	8 39
MgO,	1 18
CaO,	8 96
Na ₂ O,	3 13
K ₂ O,	1 95
H ₂ O,	1 02
	<hr/> 100 95

Propylitic rocks occur in the vicinity of large fissure-veins and vein-systems in Tertiary effusive rocks—for instance, at the Comstock, Nevada; Pachuca and Real del Monte, Mexico; in the South American Andes; and in Hungary and Transylvania. Although the propylite indicates the general metasomatic process in these veins, it is not uncommon to find rocks and soft clays containing sericite as a product of the extreme metasomatic action very close to the vein. The waters principally active during the formation of the propylitic veins probably contained only a small amount of carbon dioxide and very little lime, but may have been rich in sulphuretted hydrogen.

The filling of open spaces is a very important process in these veins, as may be expected from their formation comparatively near the surface; and this filling usually constitutes the principal ore, though altered rock, containing enough gold and silver to be classed as ore, occurs extensively in many places.

The primary character of propylite as a separate eruption is to some extent still upheld by Zirkel,* but his arguments are not convincing.

The Comstock Lode.—The relations at the Comstock lode, described by G. F. Becker,† are exceedingly interesting, because the deposit, besides being celebrated for its immense

* *Lehrbuch der Petrographie*, ii, p 485

† G. F. Becker, "Geology of the Comstock Lode," *Monograph III*, U. S. Geol. Surv

production, is a representative type. The vein, which carries both silver and gold, is surrounded by an area of extreme alteration, occupying a space of about 5 by 2 miles, affecting alike the diorite, diabase and andesite.¹ In the course of this alteration the hornblende and augite are changed to chlorite, which also infiltrates the feldspars. Pyrite is present in the rock in proportion to its alteration, and is probably developed from the ferro-magnesian silicates, to a lesser degree, from the magnetite. The feldspars are decidedly less easily altered than the silicates mentioned. Beginning alteration is made apparent by specks of calcite. Later on, quartz grains and an opaque white, doubtful substance appears. No kaolinite was recognized, and if present, it occurs in very subordinate quantities only. Epidote is more abundant near the surface than in depth, and appears to result from the further alteration of chlorite, under the influence of calcic solutions derived from the feldspars. Muscovite as a product of alteration of the feldspars is absent.

The extreme alteration is represented by the so-called clays, which were formerly supposed to consist largely of kaolin. Becker shows this assumption to be erroneous, and gives analyses to show that the clays are simply derived from the normal rocks by a partial alteration. An examination of the analyses quoted from the monograph of Clarence King,[†] in Table I, following page 152 of Becker's monograph, will show that in the diorites, andesites and diabases the Na_2O decidedly exceeds the K_2O . In two of the three analyses of "propylites," which are simply rocks subjected to incipient thermal alteration, the K_2O is present in decidedly larger quantity than the Na_2O . In the remaining "propylite" analysis, the reverse is true. The four analyses of the "clays," or the extremely altered, crushed and bleached material adjoining the veins, run as shown in table on the following page.

The quantitative relations of the alkalis clearly show a concentration of potash and a leaching of soda. There can scarcely be any doubt that these clays really consist of 30 to 40 per cent. of finely divided sericite, mixed with some quartz and residual rock.

* Without wishing to reopen the Comstock question, I would state my strong belief that these three rocks are separate and independent eruptive bodies

† "Survey of the 40th Parallel," vols. I, III, VI, *passim*

Analyses of Comstock Clays

	I	II	III	IV
	Per cent	Per cent	Per cent	Per cent
SiO ₂	60 02	59 71	65 69	39 52
TiO ₂				
Al ₂ O ₃	12 15	17 59	15 39	15 97
Fe ₂ O ₃	4 38	5 04	2 11	4 47
FeO				
MnO				
CaO	6 00	0 73	1 66	9 20
MgO	1 40	4 41	2 85	3 40
Na ₂ O	0 45	1 01	2 36	
K ₂ O	1 23	3 98	4 64	3 11
CO ₂	3 17			6 20
FeS ₂	1 84	3 58	2 84	9 18
P ₂ O ₅	0 34	trace	trace	trace
H ₂ O	8 09	4 19*	2.80*	9 95
Total	99 07	100.24	100 34	101 00

Locality
 I Yellow Jacket east clay,
 II Chollar west clay,
 III Hale and Norcross east clay,
 IV Savage second station,

Analyst
 S W. Johnson
 W G Mixter
 W G. Mixter
 S W Johnson.

The Veins of Nagyág, Hungary—In 1885, Béla von Inkey published an interesting report on the ore-deposits at Nagyág.† These consist, in brief, of a complicated system of not very persistent veins, cutting an eruptive mass of trachytic rocks breaking through Tertiary sediments, which in turn rest on older argillites. The deposits are famous as containing gold accompanied by various interesting tellurides. The whole occurrence bears in its geological relation some similarity to the deposits at Cripple Creek, Colo. The principal gangue is quartz, accompanied by galena, zinc-blende, pyrite, chalcoppyrite, etc., besides gold and rich tellurides. In addition to the quartz, various carbonates are present. The fissures are small, but contain the (generally rich) ore as the filling of open spaces. The sedimentary rocks do not in general contain much valuable ore, although such occurrences are known. The ore-shoots are chiefly confined to the eruptive mass of trachyte. In the vicinity of the mineral deposits the trachytes are quite generally changed to so-called propylitic rocks, the change

* By ignition

† *Nagyág und seine Erzlagerstätten*, by Béla von Inkey, Budapest, 1885

consisting in the development of chlorite in the ferro-magnesian minerals. It is, in fact, difficult to obtain fresh rocks anywhere in the vicinity. In the immediate vicinity of the veins, and in the whole zone in which the veins are closely massed, the rock has suffered another alteration, which von Inkey refers to as a kaolinization, in consequence of which the rock loses its normal hardness and greyish or greenish color, and is transformed into a soft brownish yellow to white mass, resembling kaolin. The last traces of hornblende and augite are lost, and only carbonates replace them. The biotite is transformed to a soft talcose substance. The magnetite is often replaced by pyrite. Only the quartz remains unaltered, and, in connection with the pseudomorphs of biotite, affords the best criterion for recognizing the trachytic nature of this highly altered rock. This modification is so clearly connected with the veins that its origin from the fissures cannot be doubted. Where the rock is not altered, rich shoots are rarely found. Von Inkey thinks that this alteration clearly indicates, not superficial waters, but thermal waters ascending on the fissures. Both kinds of alteration, the chloritic as well as the "kaolinitic," are regarded as closely related to the genesis of the veins. The chloritic modification is supposed to have resulted from a sort of hydrometamorphic action preceding the immediate formation of the veins. This so-called kaolinized rock has been examined in more detail by Dr. Kollbeck,* who showed it consists partly of sericite. Dr. Kollbeck separated the rock by means of heavy solutions, finding that, besides the sericite, it contained some pyrite (with a little arsenic, gold and silver), zircon and anatase, as well as a little apatite. The chief constituent fell between specific gravity 2.918 and 2.649, though most of it came down at 2.788. The analysis of the micaceous mineral gave the following composition. SiO_2 , 48.67; Al_2O_3 , 39.30; Fe_2O_3 , 0.30; MnO , 0.25; CaO , 0.38; MgO , 1.42; K_2O , 3.73; Na_2O , 0.13; H_2O , 5.83; CO_2 , 0.23; FeS_2 , 0.43; total, 100.67 per cent.

As may be inferred from the variability of the specific gravity, the mineral is clearly not pure muscovite, but probably a mixture of sericite and kaolinite, as is shown by the high

* *Oesterreichische Zeitschrift für Bergbau und Hüttenwesen*, 1888, pp. 25-27.

percentage of alumina and water and the low percentage of potassa.

Pachuca, Mexico.—Another type of this class of veins is described by Messrs J. Aguilera and E. Ordoñez.¹ The well-known and very productive veins of Pachuca cut a series of Tertiary effusive rocks, principal among which is a pyroxene-andesite. Rhyolite and basalt are also present, but contain, near Pachuca, no mineral veins. The deposits are typical fissure-veins, filled with a gangue of quartz carrying in fine dissemination argentite, pyrite, galena, zinc-blende, stephanite and polybasite. The value is almost exclusively in silver, very little gold occurring. There is no ruby-silver, and in depth the veins are said to be impoverished by the appearance of large quantities of barren zinc-blende. The pyrite and galena contain a little silver, but no gold. Calcite appears in subordinate and varying quantities, as the latest gangue, filling interstices between quartz crusts. Inclusions of country-rock in sharp fragments are common in the quartz. On the whole, there can be no doubt that the ore in these veins is chiefly the filling of open cavities by quartz, as in the gold-quartz veins of California.

Over a large area in the vicinity of the veins the rocks contain much chlorite and quartz, with a little calcite. Close to the veins, the alteration is most intense. The country-rock is filled with small, perfect crystals of pyrite, which is always practically barren. Its sharply developed crystal-form contrasts with the generally anhedral form of the pyrite in the vein. Black sulphides occasionally, but rarely, appear in the country-rock next to the veins. These are, of course, rich. The rocks immediately adjoining the veins contain, besides pyrite, much chlorite, also some calcite and a considerable amount of secondary quartz. The latter is so abundant that the chief alteration near the vein is often a silicification, the quartz sometimes appearing in the ground-mass, in other cases the whole rock is silicified by substitution of quartz. Chalcedony, and more rarely opal, is also found in the altered rock. In many cases, in the deeper parts of the veins, the only difference between the rocks adjoining and those more distant from the vein is in

¹ *Boletín del Instit. Geol. de Mexico*, Nos 7, 8, 9 "El Mineral de Pachuca."

the quantity of impregnating silica. The pyroxene alters to chlorite and epidote. The feldspars (oligoclase and labradorite) are often converted to calcite, epidote and quartz. Mr. Ordoñez says further that the feldspars have a marked tendency to become transformed into kaolinite (*arcilla*). As he gives no analyses of the altered rocks, it is difficult to judge whether finely divided sericite is present or not. On the whole, the similarity of this district to the Comstock, so far as the alteration is concerned, is very striking, and there is little doubt that the two deposits owe their origin to extremely similar solutions.

New Zealand.—The auriferous veins of Thames, New Zealand, are contained in andesitic rocks, which, near the fissures, have suffered considerable alteration. The character of this alteration has been described by F. W. Hutton* in a report on the rocks of the Hauraki gold-fields, which include, among others, the Thames district, and are situated near Auckland on the northern island. Triassic or pre-Triassic sediments are unconformably overlain by younger volcanic formations which contain the gold-deposits. The rocks consist largely of andesite, both augitic and hornblendic, which is accompanied by masses of tuffs and breccias. Rhyolite and dacite also occur. The alteration, chiefly of propylitic character, is distinguished by the appearance of much secondary chlorite, not only in the bisilicates but also in the ground-mass and in the feldspars, the latter, besides, altering to calcite and "kaolin." The chlorite alters again, in places, to a mineral which, from the description of the author, probably is sericite. Another common secondary product is quartz in fine aggregates. The pyrite frequently, though not always, present, is sometimes derived from magnetite. In other cases it is associated with the product of decomposition of titaniferous iron-ore, usually referred to as leucoxene. The color of the rocks subjected to the propylitic alteration is greenish grey, which, on further alteration, changes into lighter tints. The process is illustrated by several analyses by Skey, but they only throw an imperfect light upon the subject, as the alkalis are not separated, nor CO_2 and H_2O individually determined.

Prof. Hutton is a pronounced advocate of lateral secretion, and believes that the gold was derived from the surrounding volcanic rock. This conclusion is disputed by Dr. Don.†

* *Austral Ass Adv Sci*, vol 1, 1887, pp 245-274

† "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvii., 586

Alaska—The Apollo mine on Unga Island, described by G. F. Becker,^{*} is an interesting deposit in andesitic rocks. The ores consist of pyrite, galena, zinc-blende, chalcopyrite, with a little calcite. Native gold and copper occur with these ores, and the presence of a small quantity of orthoclase has also been proved. According to Becker, the ore is present exclusively as the filling of cavities, and shows beautiful comb-structure. In the vicinity of this deposit, the andesites are highly chloritic and contain abundant pyrite. Neither sericite nor carbonates are mentioned. The course of the alteration is very clearly propylitic. The pyrite in the altered rock is largely derived from the ferro-magnesian silicates.

Silver Cliff, Colorado.—The deposits of Silver Cliff should probably be referred to the propylitic class, although sericitization here also appears as a very important metasomatic characteristic. The districts of Silver Cliff and the Rosita Hills, as described by Messrs. Emmons and Cross,[†] are characterized by a complex of andesites, rhyolites and trachytes, resting on old Archean rocks and erupted through them. The igneous rocks and, to some extent, the old gneisses are traversed by a system of veins and irregular deposits carrying chiefly silver-ores, consisting of tetrahedrite, stephanite, pyrite, chalcopyrite and galena, in a gangue of barite with a little calcite. The ore consists chiefly of altered country-rock in which the different sulphides and gangue-minerals have been developed by metasomatic replacement. Mr. Emmons considers that the solutions first filled narrow fissures between sheeted rocks, and from these fissures gradually worked into the rock itself. The whole occurrence at Silver Cliff appears to show strong analogy with that of Cripple Creek and Nagyág; for in all of these places a relatively small complex of Tertiary eruptive rocks, at or near the point of eruption, has been traversed by a complicated system of fractures along which the ore has been deposited by solutions penetrating the fissures, as a later manifestation of the eruptive activity.

Over large areas the rock, especially the andesite, is much decomposed and bleached, and also contains a considerable

^{*} 18th Ann. Rept. U. S. Geol. Surv., part III, p. 83.

[†] 17th Ann. Rept. U. S. Geol. Surv., part II, pp. 269-472.

amount of pyrite. The greenish color first appearing is due to the development of chlorite, the pyroxene being replaced by chlorite, calcite and quartz. Further alteration results in a strong sericitization, and in removal of iron and lime. The biotite always changes into muscovite, which sometimes contains crystals of anatase. The lime-soda feldspars are also replaced by aggregates of muscovites, but the potash-feldspars are rarely altered until all the other minerals have been almost completely decomposed. The magnetite disappears with the silicates. Pyrite is common, and in certain cases seems to be a direct replacement of magnetite. Calcite is frequently associated with muscovite, and may replace plagioclase or augite. Mr. Cross recognized no kaolin in noteworthy amount among the products of alteration. In some instances the bleaching extends through large rock-masses, but it clearly proceeds from fissures. Near the veins, the bleached rock adjoining the small fissures may gradually shade off into fresh rock within a few feet.

A silicification is noted in some cases, especially in the case of a dike of rhyolite,^{*} which has suffered so great alteration as to be almost completely changed to quartzose fine-grained material. The andesite may also occasionally show silicification. The rhyolite is altered in some places to soft, whitish material, and in other places to hard cavernous quartzose material. The contacts of rhyolite and andesite are sometimes changed to such a degree as to make rock-determination very difficult.

Silver City, Idaho.—The fissure-vein of the Trade Dollar and Black Jack mines, Florida mountain, near Silver City, Idaho, presents some unusual features.[†] The sharply defined vein cuts across granite, basalt and rhyolite. The ores consist of argentite and chalcopyrite in a gangue of quartz and valencianite (orthoclase), forming typical fillings of open spaces. The alteration affects the various rocks somewhat differently, but the vein is undoubtedly of the propylitic class, in the formation of which alkaline carbonates and carbon-dioxide were present only in small amounts.

In the granite the adjoining rock is very slightly altered, though spaces of dissolution and crushed portions in it may be filled with quartz and valencianite.

^{*} *Loc cit*, p. 358.

[†] W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, pt. III, pp. 134-144, 174-187.

The rhyolite is extensively altered and somewhat silicified, the quartz crystals having received aureoles of the same mineral in secondary deposition. The feldspars are often converted into fine-grained quartz and sericite, the ground-mass being changed to the same minerals, and the quartz predominating. A little kaolinite is probably also present, and pyrite in small cubes is scattered through the rock. Near the underlying basalt, epidote and chlorite have been introduced into the rhyolite, indicating an upward movement of the solution.

The basalt is also considerably altered, and the character is typically propylitic, with abundant chlorite and pyrite, and slight changes otherwise in the chemical constitution.

6. *Fluoritic Gold-Tellurium Veins.*

This peculiar and interesting class of deposits, the discovery and study of which date only a few years back, is characterized by the appearance of tellurides of gold and silver, besides a little native gold; by the universal presence of (usually purple) fluorite; and by an intense metasomatic action—so that the larger proportion of the ores consists of altered country-rock. The gangue is quartz, fluorite and barite, ore-minerals, except tellurides, are not very abundantly present.

The age of these deposits, as thus far known, is probably Tertiary, following the outbreaks of phonolitic magmas, with which all of the occurrences show a remarkable connection. The depositing waters must have been poor in carbon-dioxide, alkaline and earthy carbonates, but contained more or less fluorine as hydrofluoric acid, which is possibly indicated by the abundant spaces of dissolution in the granite of Cripple Creek. Or else (and this was probably the more common case) they contained alkaline fluorides. Though the veins are closely connected with the eruption of phonolitic magma referred to, it is not believed that the conditions of deposition were of pneumatolytic character, but rather that they were normally hydrothermal.

Cripple Creek.—The geology and mineral deposits of the Cripple Creek district, Colo., have been examined by Whitman Cross and R. A. F. Penrose.* The general occurrence of the veins is somewhat analogous to that of Nagyág, Hungary, and

* 16th Annual Report U S Geol Surv, part ii

Silver Chff, Colorado, inasmuch as they cut igneous masses, here consisting of andesite and phonolite, and occur in close proximity to the original *locus* of eruption of these rocks. The veins, of which there are a great number, contain native gold, tellurides and pyrite, together with a little galena and zinc-blende. Silver is present in very small amounts only. The gangue consists of quartz, fluorite and barite. Prof Penrose designates the veins as very largely replacement veins, formed by metasomatic action of the solutions ascending in narrow fissures on the surrounding country-rock. Filling of open fissures exists to a subordinate extent. Large masses of the volcanic rocks, especially the porous tuffs, were subjected to thermal action prior to the formation of some of the fissures. The alteration results in silicification, kaolinization and some sericitization. In the breccia and tuff, the process consists in the total destruction of the dark silicates, and the substitution of a white mica for them. The feldspar changes to muscovite or kaolin, the only fresh remaining crystals consist of apatite, and the rocks are greatly impregnated with pyrite. In some places the alteration consists in a silicification, but more commonly muscovite or kaolin are the minerals formed. Penrose says also that kaolin occurs in the veins in irregular masses, mixed with quartz. Three analyses of this product show that it is a normal kaolin. While it is conceded that the kaolin is to some extent the result of surface alteration, its formation was chiefly earlier than the development of this superficial alteration. The quantity of kaolin, he says, does not diminish in depth, where it still occurs associated with unaltered sulphides.

An opaline silica is also found in the veins, often appearing like red, brilliant, conchoidal jasper. An analysis of it shows SiO_2 , 72.46, Al_2O_3 , 2.52, Fe_2O_3 , 17.88, CaO , 0.14, MgO , trace; K_2O , 1.08, Na_2O , 0.06, H_2O , 5.70, total, 99.84 per cent.

The origin of this product is not stated, but it is not improbably the result of extreme alteration of a volcanic rock. It is interesting to note that among the alkalis K_2O strongly predominates, and, to judge from the analysis, the rock must contain about 10 per cent. of sericite.

During the last year I had opportunity to examine a suite of specimens collected by Mr S F Emmons from the Independence and Portland mines, and some of the results are here

published with his permission. At these mines, the narrow fissure along which the replacement took place cuts both the granite and the andesite-granite breccia, and in places follows a dike of phonolite. The specimens clearly bear out previous statements as to replacement. In addition to the fluorite, secondary orthoclase, or valencianite, was recognized as a universally present gangue-mineral. The granite-ore from both mines consists of a coarsely granular rock, largely of microcline and quartz, made cellular and porous by spaces of dissolution. The cavities are coated with abundant small and clear crystals of valencianite showing the usual combination of prism and dome, also with a little pyrite, gold, and small cubes of fluorite.* The crystals of valencianite were isolated and conclusively identified by qualitative analysis and tests. Microscopic analysis reveals but little alteration in the granite, though the biotite foils are replaced by a substance which appears to be valencianite. The feldspars contain a few shreds of sericite, and pentagonal crystals of pyrite are scattered through feldspar and altered biotite. In places, small replacement-veinlets of fluorite and quartz traverse the feldspar. The cavities of dissolution apparently result from the removal of both quartz and microcline. Some of them are filled with quartz, valencianite and pyrite; the secondary feldspar often being deposited with orientation parallel to that of older grains. A few grains of secondary feldspar show microcline structure, but most of them are simple individuals. These filled spaces, characterized by crustification, are illustrated in Fig. 11.

The processes of replacement are remarkably variable. In some of the granite-andesite breccias the result is quartz, valencianite, fluorite and pyrite. Fig. 10 shows how the replacement progresses in a grain of orthoclase. Fig. 8 shows a filled veinlet in the same breccia, which by means of a narrow crack connects with the feldspar grains just mentioned. The valencianite shows crustification, while the fluorite and pyrite, by corroding the walls, indicate partial metasomatic action.

Some of the phonolites of the Independence mine are porous siliceous rocks, completely replaced with quartz, valencianite crystals, pyrite, and a few grains of a telluride of gold and

* Confer. W. Lindgren, "The Gold and Silver Veins of Silver City," 20th Ann. Rept. U. S. Geol. Surv., part III, p. 167.

silver. Other specimens show only incipient alteration, being impregnated with pyrite crystals and containing a few per cent. of sericite, they contain, besides, spaces of dissolution filled with quartz, fluorite and valencianite. Certain fine-grained granitic breccias from the Annie Lee shoot, in the Portland mine, show a most peculiar alteration, the quartz and orthoclase being both replaced by calcite, pyrite and secondary orthoclase. The final result of the alteration of phonolite is, in many cases, a purple fine-grained rock consisting of quartz, fluorite and pyrite; as usual, the fluorite is crystallized, and the quartz also shows, to some extent, idiomorphic outlines (Fig 9).

Other Occurrences—To this class belong also the so-called Potsdam tellurium-ores of the Black Hills, Dakota, described by Devereux, Carpenter, F. Clemens Smith, and lately by J. D. Irving*. According to Mr Irving, the irregular deposits are connected with fissures, and consist in a replacement of limestone by silica, with fluorite, and gold, partly in the form of tellurides. While the age of these deposits is not fully known, they are believed to be genetically connected with phonolitic and tinguaitic dikes of Tertiary age.

Mr. W. H. Weed† has described interesting occurrences of the same type from the Judith mountains in northern Montana. The deposits, though, strictly speaking, not fissure-veins, are still more or less clearly connected with fractures, and are found in the brecciated contact-zone between limestone and intrusive masses of acidic porphyry. The principal gangue-minerals are quartz and purple fluorite, the ore-minerals being native gold and tellurides of gold and silver. The mode of ore-deposition is certainly a replacement of limestone, the fluorite occurring in more or less sharply defined patches in the limestone breccia. From a specimen which Mr Weed kindly selected for me a section was cut, which is partly illustrated in Fig 14. The invasion of the normal limestone, still carrying organic remains, by the crystallizing fluorite, is well shown, as well as the incipient silicification which accompanied the metasomatic action. Much secondary silica, replacing limestone,

* "A Contribution to the Geology of the Northern Black Hills," *Ann. N. Y. Acad. Sci.*, vol. xii, No. 9, pp. 297-314.

† 18th Ann. Rept. U. S. Geol. Surv., part iii, p. 588.

also occurs in jaspery or cherty form. Small cubes of fluorite, found in the fresh limestone, represent places of incipient fluoritization. Dikes and sheets of phonolitic rocks are found in the vicinity of the deposits. A deposit occurring in rhyolite porphyry not far from the limestone shows strong alteration of the country-rock. The feldspar is here changed to sericite, the ferro-magnesian minerals are transformed to calcite, and abundant small crystals of pyrite appear in the rock. Fluorite is also present on some of the veins in rhyolite porphyries. Mr. Weed regards the deposits as possibly of pneumatolytic origin. It is scarcely necessary, however, to assume the fluorine to have been present in the form of free hydrofluoric acid (compare pp. 601 and 604).

Similar deposits, with purple fluorite and tellurides, are also described by Mr. Weed from the Little Rocky Mountains, in Montana.*

7 *Sericitic and Kaolinitic Gold- and Silver-Veins.*

General Remarks—This class has not been studied as much as some of the other subdivisions, but many deposits will probably be found to belong to it. Apparently the pure aluminic silicate cannot be formed when the generating waters contain much carbon dioxide or alkaline carbonates. But it does form under the influence of some waters containing a small amount of these reagents, and also in the presence of sulphuric acid, which, as is well known, rapidly attacks the feldspars. Even under the latter two conditions, some sericite is ordinarily also formed; and I am not aware of any veins in which kaolinite forms without sericite. The class may be subdivided according to the absence or presence of silicification.

The Freiberg Veins—As is well known, several very different kinds of veins appear in the Freiberg district, practically all, however, being sharply defined fissure-veins in gneiss, in which the filling of open spaces constitutes the only ore; extensive zones of alteration are absent. It is a peculiar fact that very little is known of the metasomatic processes affecting the country-rock at this celebrated locality, no chemical examinations having been made to determine how the various classes of

* *Journal of Geol.*, vol. 14, pp. 399-428 (1896)

veins may differ in their metasomatic products. A letter from Prof. Beck, of Freiberg, informs me that Prof A. W. Stelzner devoted much time during the last years of his life to the examination of the changes in the country-rock adjoining the veins, but that his manuscript notes have never been published.

W. Vogelgesang,* in describing the veins south and southeast of Freiberg containing carbonates and rich silver-ores, describes the impregnation of the adjoining rock with ores. He mentions the occasional introduction of argentite and native silver into the gneiss, also, in places, of arsenopyrite, pyrite, chalcopyrite, zinc-blende and galena. The impregnation with silver-ores appears only in especially rich places along the vein. In one case, however, the impregnated rock appears as an irregular, limited mass, almost entirely independent of the direction of the vein. In another locality, chalcopyrite and bornite were found in the wall-rock, while the filling of the vein contained neither. In the same paper, the author describes the alteration of the so-called normal gneiss of Freiberg near the veins of the *Kiesige Bleiformalion*. The mica is the first mineral attacked; the second is the feldspar. The former acquires a silvery-white color, often connected with a chloritic appearance. The feldspar is changed to a white "kaolin," and the whole rock is bleached white. By extreme alteration, the quartz disappears, and the rock forms a white or yellowish-white talc-like mass. The altered rock is frequently, in fact usually, filled with arsenopyrite. Some of the crystals are large; others microscopic, and their amount may so increase as to form a connected, compact mass of arsenopyrite. All these crystals are twins, excellently developed, with perfect faces. This description refers especially to the *Dietrich Stehender* vein.† In the foot-wall, and partly also in the hanging-wall, of this altered mass appears a rock, recognizable as the ordinary grey gneiss of Freiberg. It contains no arsenopyrite but is strongly impregnated with galena, arranged in curved streaks parallel to the schistosity, and replacing one constituent of the rock, namely, the feldspar. The altered rocks have been analyzed; but the determination of alkalis being omitted, the analyses have no special value.

* Bernard Cotta, *Gangstudien*, vol. ii., Freiberg, 1854, p. 78.

† The sericite from this vein has been analyzed by H. Schulze, see page 609.

The rock adjoining the Gotthold-Stehender vein is likewise strongly impregnated; but here, besides arsenopyrite, galena, chalcopyrite, pyrite and zinc-blende are also found.

As early as 1883 and 1884 Stelzner^{*} devoted considerable attention to the examination of the soft and altered rock adjoining the veins of Freiberg. These altered rocks are also usually impregnated with small crystals of arsenopyrite, or pyrite, or (more rarely) zinc-blende and galena. In the normal gneiss of Freiberg, which Prof. Stelzner subjected to separation by heavy solutions, he found much zircon, as well as a little tourmaline and a large quantity of apatite. All three of these minerals were also separated from the altered wall-rocks in the crystalline shape which they had had in the fresh rock; hence none of them had been attacked. He observes further that the quartz, feldspar and biotite of the fresh gneiss is completely or almost completely changed into white potassium mica, forming, in small hexagonal or irregular foils, the chief mass of the rock. This secondary mica contains, according to analysis by Dr. Schulze, as much as 0.41 per cent. of TiO_2 and 0.54 per cent. of SnO_2 . As newly-formed minerals in the altered rock, appear small crystals of quartz, rutile and anatase. In certain of the examined rocks only rutile was found, in others only anatase (octahedrite), but both were present as sharply defined small crystals. These two minerals are considered as resulting from a decomposition of the biotite, which is rich in titanîc acid. In analyzing the heaviest part obtained by the Thoulet solution from the altered rock close to one of the veins, it was found that cassiterite was present in notable quantity. Whether this tin-ore resulted from the decomposition of the biotite, or whether, like the arsenopyrite, it had been introduced from the vein-fissure, is not certain. The latter hypothesis is probable; for the black zinc-blende of the same vein (the Carl Stehender) contains small, but numerous, crystals of cassiterite.

Examination of the fresh gneisses of Freiberg discloses the presence of pyrrhotite, pyrite, and probably also a little arsenopyrite. These are presumably primary; at least the statement of Prof. Stelzner is probably to be interpreted in this sense.

The first attempt to examine the altered wall-rocks in a sci-

* A. W. Stelzner, "Studies of the Gneiss of Freiberg and its Products of Alteration" *Neues Jahrbuch*, 1884, vol. 1, p. 271.

entific manner was made by Prof Th. Scheerer,* in connection with his classic paper on the gneissic rocks from the vicinity of Freiberg. According to Scheerer, the normal character of the grey gneiss is always more or less changed in the vicinity of mineral veins, the extension of this alteration being, in general, dependent upon the width of the vein. The mica has turned into a light greenish-grey or white talcose mass, and the whole rock is softened and easily crushed. The width of this alteration ranges from a few inches up to 6 feet. In the porous gneiss, small bodies of pyrite, zinc-blende and galena have been formed, partly as separate crystals, and partly in little veinlets. Prof. Scheerer examined especially a gneiss closely adjoining the Erzengel vein belonging to the *Kiesige Bleibformation*, in the Himmelfahrt mine. The specimen was taken from one of the deep levels, thus eliminating the action of surface-water. The analysis gave: SiO_2 , 61.69; TiO_2 , 0.73; Al_2O_3 , 21.74; Fe_2O_3 , 0.43; CaO , 1.07; MgO , 1.15; K_2O , 2.69; Na_2O , 0.30; H_2O , 3.96; fluorite, 1.20; pyrite, 4.26; chalcopyrite, 0.23; galena, 0.09; argentite, trace, total, 99.54 per cent.

Scheerer recalculated this analysis on the basis of constant alumina and, combining the result with the analyses of the fresh rock, obtained the table on the following page. The assumed constancy of the alumina is probably not quite correct, but offers an easy and fairly accurate way of approximately judging the changes that have taken place.

This result is remarkable in many respects. First, we note that a very decided removal of substance has taken place. Counting by equal weights, only 5 parts in 100 have been added (even less, if we consider that the Fe of FeS is derived from Fe_2O_3 and FeO in the fresh rock) while no less than 42.45 parts have been carried away. This contrasts strongly with the results obtained from gold-quartz veins in California and Idaho. Of the silica, 26.62 parts or 40 per cent is removed. The total bases, except alumina, have been diminished to the extent of 81.01 per cent. Both K_2O and Na_2O have been removed, the former, however, in much smaller proportion than the latter. Lime, magnesia and iron have also been very greatly reduced. A large part of the iron, however, appears to

* *Zeitschr. d. d. geol. Ges.*, vol. xiv, p. 87 (1862).

	Normal Grey Gneiss	Altered Grey Gneiss	Additions and Subtractions Suffered by the Altered Rock
	Per cent	Per cent	Per cent
SiO ₂	65.42	38.80	-26.62
TiO ₂	1.05	0.46	-0.59
Al ₂ O ₃	13.68	13.68	
Fe ₂ O ₃	4.26	0.27	-3.99
FeO	2.88		-2.88
CaO	1.44	0.67	-0.77
MgO	2.66	0.73	-1.93
K ₂ O	6.18	1.70	-4.48
Na ₂ O	1.38	0.19	-1.19
H ₂ O	1.05	2.49	+1.44
Fluorite		0.76	+0.76
Pyrite	trace	2.68	+2.68
Chalcopyrite	trace	0.15	+0.15
Galena	trace	0.06	+0.06
Argentite		trace	trace
	100.00	62.64	-42.45
			+5.09
			37.36
		100.00	

have been transformed into pyrite. There are no carbonates at all, while a little fluorite has formed

Of course, no microscopic diagnosis of Scheerer's specimens is now available. But from Stelzner's later separations and Schulze's analysis it is clear that considerable sericite is present. An attempt to calculate Scheerer's analysis shows at once that kaolinite is also present. A rough calculation gives the following result Quartz, 40; sericite, 32, chlorite, 3.20; kaolinite, 17.70, titanite, 1.90; fluorite, 1.20; pyrite, 4.26, chalcopyrite, 0.23; galena, 0.09; total, 100.58 per cent.

In this calculation K₂O + Na₂O are taken as a basis for sericite, according to Schulze's analysis; MgO is calculated as chlorite; the remaining H₂O is calculated, with proper quantities of Al₂O₃ and SiO₂, as kaolinite, and there is a small excess of CaO, possibly belonging to apatite. P₂O₅ is not determined in the analysis. But there remains also an excess of 4 per cent of Al₂O₃, which is inexplicable on the basis of this assumed mineral composition, and it is difficult to see how this should be treated. Possibly the determination of H₂O is a little too low. At any rate, a considerable amount of kaolinite is surely present. This result is of great interest. The strong leaching of SiO₂ and bases, as well as the presence of kaolinite together

with sericite, points to a process and to water very different from those by which sericite alone is produced. It is not out of place in this connection to call attention to the presence of fluorite and to the close relationship which, as indicated by Dalmer, exists between the cassiterite-veins and those of the *Kiesige Blei* formation of the Erzgebirge, a relationship still further emphasized by the occurrence of cassiterite in the Freiberg veins. Scheerer believed that the grey gneiss, by reason of its easily-attacked biotite, had a precipitating influence on the mineral waters. The red gneiss, containing muscovite in general, carries no large bodies of ore.

De Lamar, Idaho.—The quartz veins of De Lamar, Idaho, belong to that class in which the alteration of the country-rock results in sericite, kaolinite and quartz*. These ores, which carry finely-divided gold, together with some rich silver minerals, are peculiar, because the quartz now constituting the filling is pseudomorphic after a former vein-filling of calcite. The country-rock has undergone two corresponding changes: the first consisting in a normal sericitization; the second in a silicification, probably under the influence of waters containing sulphuric acid. The final result is that the rhyolite is converted to a silicified rock, in which the structure is plainly preserved. The phenocrysts of quartz have received aureoles of secondary silica, and the feldspars are fully converted into fine-grained aggregates of quartz. The composition is as follows: Sericite, 15.43; kaolinite, 3.81; quartz, 78.73; pyrite, 0.90, and water (hygroscopic), 0.51; total, 99.38 per cent.

Expressed quantitatively, the process appears to consist in the loss of nearly all of the soda, half of the alumina and much of the ferrous and ferric oxide; and finally, in the addition of several per cent of silica. The pseudomorphic filling consists of crossing laminae of quartz, each consisting of a thin plate of microcrystalline silica, coated on both sides with small quartz crystals.

The character of the process involved in this change from calcite to quartz is probably as follows. Calcite-filling in veins is often characterized by a prevalence of long, slender or spear-shaped grains. The solutions carrying silica penetrate along

* W. Lindgren, 20th Ann. Rept. U. S. Geol. Surv., part iii., p. 178 et seq.

the contact-planes of these grains and deposit their plates of microcrystalline quartz in the place of dissolved calcite, from these medial plates small quartz crystals grow into and gradually replace the calcite on both sides. The pseudomorphic plates do not, as a rule, follow the cleavage-planes, hence there may be in some cases considerable difficulty in determining the original mineral replaced by the quartz. The subject is more fully treated in my report, cited above.

Summit District, Colorado—Some remarkable ore-deposits in the Summit district, Rio Grande county, Colo., have been described by R. C. Hills* as masses of quartz resulting from the alteration and silicification of eruptive rocks along contact-planes, especially between rhyolite and trachyte-breccia. The quartz, which contains gold, enargite, pyrite, galena and zinc-blende, gradually merges into rhyolite, varying in thickness from 3 to 30 feet. Thus silicification of the rhyolite is evident, and has resulted in a change of the ground-mass to compact quartz, while the phenocrysts of that mineral remain intact and conspicuous. The sanidine has been removed, and pseudomorphic quartz has been deposited. The surrounding rock is notably kaolinized, and contains no lime or potash. The alteration probably took place less than 300 ft. below the original surface.

The following is suggested in explanation of the chemical processes. Silica is practically insoluble in solutions containing sulphates and chlorides, hydrogen sulphide and free sulphuric acid. Under these conditions, aluminum silicates are dissolved and sulphates or chlorides of aluminum are formed, with simultaneous separation of silica, and to sulphuric acid as a reagent the writer believes the alteration to be chiefly due. Whether the metallic minerals were deposited simultaneously with this alteration, or subsequently, is left an open question, though it is believed that their simultaneous deposition would be possible.

8. *Sericitic and Calcitic Gold-Silver Veins.*

This important metasomatic class comprises an enormous number of veins, differing widely in age and in the character

* *Proc. Colorado Sci. Soc.*, vol 1, p 20

of the country-rock, but usually characterized by quartz-filling, enclosing auriferous and argentiferous sulphides (often also free gold), while the adjoining rock for a short distance on both sides is converted into an aggregate of quartz, sericite and calcite, with some metasomatic sulphides. Extensive alteration-zones are not common; and sometimes fresh rock may adjoin the vein. The relative quantity of sericite and carbonates may differ considerably, even in the same mine.

The Gold-Quartz Veins of California—These, perhaps the most prominent representatives of the class, have been studied in some detail.* The gold-quartz veins of California are fissure-veins of Cretaceous age, largely filled with quartz along open spaces. A small amount of calcite may also occur. The ore-minerals comprise native gold, present in a free state at all depths reached hitherto, and a small amount of sulphides consisting of pyrite (never marcasite and rarely pyrrhotite), galena, zinc-blende, arsenopyrite and chalcopyrite. Tellurides are often found, but in small quantity only. The veins are practically independent of the character of the country-rock, cutting almost all the sedimentary and igneous rocks of the Sierra Nevada. Adjoining the veins the country-rock, for a variable distance, but seldom exceeding a few feet, is nearly always altered by metasomatic processes. Clay-slates and siliceous schists have been apparently least affected in this way, except that they are generally impregnated with pyrite. More detailed chemical examinations will probably show that even these rocks have been altered more than their appearance would suggest.

In the ordinary course of the metasomatic process, augite, hornblende, epidote, biotite and feldspars are first vigorously attacked. The ferromagnesian silicates are often converted into large foils of muscovite. The alteration proceeds along cracks and cleavage-planes, and a finely felted aggregate of sericite and calcite invades the grains until the replacement is complete. Though the ferromagnesian silicates are, for the most part, directly converted into the minerals mentioned, they form also a chlorite, very rich in iron, as an intermediate

* W. Lindgren, *Bull. Geol. Soc. Am.*, vol. vi, pp. 221-240, also in *U. S. Geol. Surv.*, 14th Ann. Rept., pt. II, pp. 249 to 284, and 17th Ann. Rept., pt. II, pp. 1 to 262.

stage, which is converted later into sericite. An interlacing structure of sericite foils, the triangular or polygonal interstices of which are filled with calcite (Fig. 12), is often noted. The quartz is also attacked, but with more difficulty; and in no case is it completely replaced by the attacking sericite-carbonate aggregate (Fig. 15). Magnetite seems to be converted mostly into ferrous carbonate, and ilmenite to rutile. Sharp cubes of pyrite form in the new aggregates, but also in the fresh primary minerals. The only other sulphide found is arsenopyrite, which, in some mines, appears as sharply defined rhombic crystals. The sulphides sometimes include fibers of sericite. The result of the process is the conversion of the rock to sericite, carbonates, quartz and pyrite, with retention of the original structure as shown in Fig. 27. The alteration of serpentine has already been referred to.

From many analyses the following eight are selected, A and A₁, B and B₁, etc., being respectively the unaltered and altered rock from each locality.

TABLE I.—*Analyses of Metasomatic Rocks from Gold-Quartz Veins.*

	A	A ₁	B	B ₁	C	C ₁	D	D ₁
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
SiO ₂	65.54	46.13	45.56	37.01	66.55	56.25	51.01	45.74
TiO ₂	39	67	1.11	85	38	25	.98	36
Al ₂ O ₃	16.52	15.82	14.15	12.99	16.15	17.65	11.89	5.29
Fe ₂ O ₃	1.40	89	1.20	43	1.52	.76	1.57	13
FeO	2.49	2.27	9.83	3.57	2.36	2.64	6.08	2.06
FeS ₂		1.61	7.86	7.99	.02	2.87	1.73	49
Cu ₂ S			10	trace			trace	
MnO . . . .	.06	.09	.25	.24	10	none	trace	.26
NiO, ZnO		trace	trace	trace				
CaO	4.88	10.68	2.30	9.78	4.53	4.46	10.36	23.85
SrO	not det	trace	trace	trace	trace		none	none
BaO	not det	trace	trace	trace	.07	.03	none	trace
MgO	2.52	2.13	6.76	5.49	1.74	1.69	8.87	.94
K ₂ O	1.95	5.30	1.18	4.02	2.65	6.01	15	1.29
Na ₂ O	4.09	17	1.57	.13	3.40	30	4.17	.11
Li ₂ O		trace	trace	trace	trace			trace
H ₂ O below 110° C		12	23	13	18	30	24	22
H ₂ O above 110° C . . . .	.59	2.42	4.84	1.92	72	2.36	2.09	1.07
P ₂ O ₅ . . . .	.18	10	14	.06	10	.21	17	.07
SO ₃ . . . .			.03	.04				
CO ₂		11.24	3.04	15.04		4.82		18.91
Total	100.61	99.64	100.15	99.69	100.57	100.60	99.31	100.79

Probably present as Fe₂S₃.

A, Fresh granodiorite, Lincoln, Placer Co Though not adjoining the vein, it indicates closely the actual composition of the fresh wall-rock W F Hillebrand, analyst —A₁, Altered granodiorite, Plantz vein, Ophir, Placer Co W F Hillebrand, analyst —B, Amphibolite schist, Mina Rica vein, Ophir, Placer Co Fairly fresh, but contains pyrite and calcite W F Hillebrand, analyst —B₁, Completely altered amphibolite schist, Coniad vein, Ophir, Placer Co W F Hillebrand, analyst —C, Fresh granodiorite, Nevada City, Nevada Co W F Hillebrand, analyst —C₁, Altered granodiorite, Bellefontaine mine, Nevada City George Steiger, analyst —D, Fresh diabase, Grass Valley N H Stokes, analyst —D₁, Altered diabase, North Star mine, Grass Valley W F Hillebrand, analyst

From the chemical and microscopical data the following compositions may be calculated (see reports cited). The only difference from the sources quoted is due to the fact that by later chemical examination the titanium mineral present has been shown to be rutile instead of titanite.

TABLE II — *Mineralogical Composition of the Altered Rocks of Table I*

	A ₁	B ₁	C ₁	D ₁
	Per cent	Per cent	Per cent	Per cent
Quartz	16 00	24 00	25 00	35 00
Sericite (with a little chlorite)	41 76	46 97	61 46	21 20
Calcite	17 53	18 87	7 23	42 15
Magnesite	9 67	2 93	2 70	71
Siderite	5 76	3 67	58	
Rhodonite	42	14		
Rutile	85	87	25	36
Pyrite	7 99	1 61	2 87	50
Apatite	13	22	46	15
Total	100 11	99 08	100 55	100 07

As it seems probable that the alumina has remained fairly constant in the first three pairs of analyses in Table I, they may be directly compared for an approximate review of the chemical changes affected. A recalculation on the basis of constant alumina seemed scarcely worth while.

The silica has been in all cases greatly reduced. Except in A, which is not from the immediate vicinity of the vein of A₁, the titanite acid has decreased. Ferrous and ferric oxide are both reduced—the latter more than the former; and the whole or a part of this loss reappears as pyrite. Lime shows great increase except in C, where it is constant. Baryta in C shows partial loss. The loss of magnesia is considerable, except in C,

where it is slight. Potassa is strongly increased throughout, and there is a corresponding loss of soda

D₁ differs from the rest in an exceptionally high percentage of introduced lime and carbon-dioxide, and a corresponding loss of magnesia. Moreover, the alumina is so low that removal of this constituent must be supposed to have taken place.

The characteristic features of the process seem to consist in the decrease of silica, magnesia and soda, and increase of lime, potassa and carbon-dioxide—this calcitic altered rock strongly contrasting with the quartz-filled veins. Sufficient data are not available for the accurate determination of change of volume during the process, and of the actual losses and gains. They could probably be determined by analyses and specific gravity determinations of very carefully selected samples of the fresh rocks, and of altered rocks immediately adjacent to them. It seems probable that, in most cases, the added material has more than balanced the losses.

Idaho Types—In the Rocky Mountain region appear other types related to that of California. These gold-quartz veins cut granites, diorites and various porphyries, and, like the California veins, are of pre-Tertiary, probably Cretaceous, age. They carry a strong percentage of sulphurets, but generally only a subordinate amount of free gold, most of the gold being closely held in the sulphides. The filling constitutes the rich ore, but the narrow zone of metasomatic rock may also yield some low-grade ore. In general character, the metasomatic action is similar to that of the California veins, though the details of chemical change may differ. Galena, zinc-blende and chalcopryite, and occasionally also free gold, may appear in the altered rocks. The carbonates are less plentiful, and lime is more often subtracted than added. The following analyses illustrate the chemical changes in two prominent types. E and E₁ are the fresh and altered rock from Willow Creek district, Boise county. The narrow quartz-veins carry scarcely any free gold, but much auriferous galena, pyrite, arsenopyrite and zinc-blende. F and F₁ are the fresh and altered rock from the Croesus mine, Wood River district, Blaine county. The narrow streaks of filling here consist of quartz, siderite, pyrrhotite and chalcopryite, with a little galena, arsenopyrite and zinc-

blende. Here again only a fraction of the gold is in free state. The ore contains very little silver.*

TABLE III.—*Analyses of Fresh and Altered Rocks from Gold-Quartz Veins.†*

	E	E ₁	F	F ₁
SiO ₂	65 23	66 66	57 78	58 01
TiO ₂	66	49	1 01	1 08
Al ₂ O ₃	16 94	14 26	16 28	15 72
Fe ₂ O ₃	1 60	.67	1 02	.64
FeO	1 91	1 33	4 92	3 87
CoO, NiO			.02	none
MnO	trace	trace	15	17
CaO	3 85	3 37	6 65	2 15
SrO			.07	none
BaO	19	none	12	trace?
MgO	1 31	.95	4 60	2 07
K ₂ O	3 02	4 19	2 22	4 79
Na ₂ O	3 57	none	3 25	10
H ₂ O below 100° C	18	36	34	31
H ₂ O above 100° C	88	2 16	92	2 71
P ₂ O ₅	19	17	30	31
CO ₂	25	3 67	15	2 86
S	none	.95	.02	1 25
Fe		84		1 52
Co, Ni				12
Pb				86
Cu				.05
As				1 65
Total	99 78	100 07	99 82	100.24

E, Fresh granitic rock immediately adjoining the Silver Wreath quartz vein, Willow Creek, Idaho. E₁, Altered rock, adjoining the same vein. F, Fresh quartz-pyroxene-diorite, adjoining the Croesus vein, Hailey, Idaho. F₁, Altered rock adjoining the same vein.

The composition of the altered rocks may be calculated as shown in table on page 670.

The appearance of the altered rock F₁ from the Croesus mine is shown in Fig. 25.

The specific gravity of E is 2.714. From the mineralogical composition given in the report quoted the specific gravity is calculated to 2.720, which is a close agreement, the difference possibly indicating a very slight porosity ‡

* For full calculations and description of E and E₁ see W. Lindgren, 18th Ann. Rept. U. S. Geol. Surv., part III, p. 640; for F and F₁ see W. Lindgren, 20th Ann. Rept. U. S. Geol. Surv., part III, p. 211-232.

† Analyst, W. F. Hillebrand.

‡ In this calculation the following figures for specific gravity are used: quartz, 2.65; sericite, 2.83; biotite, 3.00; oligoclase, 2.65; orthoclase, 2.56.

TABLE IV.—*Mineralogical Composition of E_1 and F_1 , in Table III.*

	E_1	F_1
Quartz .	42 00	36 18
Sericite .	46 84	38 18
Chlorite		11 76
Calcite	4 80	3 11
Magnetite	1 96	1 26
Siderite	1 45	2 19
Rutile .	49	1 08
Apatite		72
Pyrite	1 78	58
Pyrrhotite		15
Zinc-blende.		trace
Galena .		99
Chalcopyrite		15
Arsenopyrite		3 58
Total	99 32	99 93

The measured specific gravity of E_1 is 2 774, indicating that the rock alters to denser minerals. The calculation of the same specific gravity from Table IV. gives 2 796, which shows a decided porosity of the altered rock. Under these circumstances, no evidence of pressure being noted, it may be assumed with fair accuracy that no considerable change in volume has taken place, and by multiplying the percentages of E and E_1 by 2.714 and 2 774 respectively, and comparing the results, the absolute gains and losses per cubic meter may be obtained (see Table V.).

In the same manner the measured specific gravities of F and F_1 are compared with the calculated specific gravities.¹ This shows that similar conditions prevail here, the porosity being greater. By multiplying the percentages of F and F_1 by the measured specific gravities, and comparing these data, the absolute gains and losses are again obtained.

During the alteration of E to E_1 , 291 kilograms were added and 229 lost per cubic meter; the net total being a gain of 62 kilos. During the alteration of F to F_1 , 416 kilograms were added and 333 lost per cubic meter; the net total being a gain 83 kilos.

A perusal of the table will show very similar results in the

TABLE V — *Gains and Losses per Cubic Meter of E and F, Table III.*

	E				F			
	GAIN		LOSS		GAIN		LOSS	
	Per Cubic Meter of E	Percentage of, for Each Constituent	Per Cubic Meter of E	Percentage of, for Each Constituent	Per Cubic Meter of F	Percentage of, for Each Constituent	Per Cubic Meter of F	Percentage of, for Each Constituent
	Kilos	Per cent	Kilos	Per cent	Kilos	Per cent	Kilos	Per cent
SiO ₂	79	4.5			48	2.9		
TiO ₂			4	22.2	2	6.9		
Al ₂ O ₃			64	13.9			4	9
Fe ₂ O ₃			24	55.8			10	34.5
FeO			15	28.8			27	19.4
CoO, NiO							1	100.0
MnO					1	25.0		
CaO			11	10.5			126	67.0
SrO							2	100.0
BaO			5	100.0			4	100.0
MgO			9	25.7			70	53.9
K ₂ O	34	41.5			76	120.6		
Na ₂ O			97	100.0			89	96.7
H ₂ O above 105° C	36	150.0			53	203.8		
P ₂ O ₅	0		0		0		0	
CO ₂	93	nearly all			79	nearly all		
S	26	all			35	nearly all		
Fe	23	all			44	all		
Co, Ni					4	all		
Pb					24	all		
Cu					2	all		
As					48	all		
Total	291		229		416		333	

two rocks a moderate addition of silica and a strong gain of potassa, nearly complete loss of soda, baryta and strontia; partial loss of alumina, magnesia and lime, F, however, losing much more lime than E. In E₁ the amounts lost of Fe₂O₃ and FeO are nearly completely converted into Fe (in FeS₂). In F these losses are less and not sufficient to account for the gain of Fe; consequently iron must have been added. Phosphoric acid is constant, consistently with the fresh state of the apatite.

San Juan, Colorado — In the San Juan region, southwestern Colorado, are vast eruptive masses of andesites and rhyolites,

with their accompanying tuffs and breccias. Some of the gold-quartz veins of Tertiary age occurring in these rocks at Telluride have been described by Mr. C. W. Purington.¹ The ores consist of quartz containing native gold, with pyrite, galena and other sulphides. In some localities silver is also present in considerable amount. The principal gangue is quartz, though carbonates also are occasionally present, and fluorite in considerable quantities is mentioned from the Tomboy vein. This is worthy of note; since, in ordinary gold-quartz veins fluorite, if not entirely absent, at least is exceedingly rare. The quartz forms, as a rule, a well-defined filling of open cavities, and the principal ore is of this character, and not altered country-rock. There are, however, more or less wide zones of partial alteration alongside the veins. The veins are often accompanied by large amounts of white, soft clay-like material, which probably is extremely altered country-rock. All of this appears to be sericite. Mr. Purington mentions having failed to establish the presence of kaolinite, except in one or two places. The ordinary course of alteration in the diorites, andesites and breccias is distinguished by the development of much calcite and sericite, and is consequently very similar to the metasomatic processes characterizing the California quartz-veins. The altered rocks contain small, abundant and sharply defined crystals of pyrite, more rarely of galena. Much of this pyrite fills the spaces formerly occupied by ferro-magnesian silicates. This pyrite is of low value, compared with the massive mineral occurring in the vein-filling. The percentage of silica in the altered rock is low, and contrasts with the abundant quartz on the veins.

Rhyolite adjoining the veins is changed to felted sericite and some carbonates, as well as pyrite.

As an exceptional process Mr. Purington mentions a complete silicification of the diorite from the hanging-wall of the Butterfly vein, in the Terrible mine. This diorite, which consists of labradorite, hornblende and a little biotite, shows a complete replacement of the feldspar by cryptocrystalline silica, while the hornblende is replaced by pyrite. There is a little sericite, but no carbonate present. The cause of this abnormal altera-

¹ 18th Ann. Rept. U. S. Geol. Surv., part iii, pp 745-846.

tion might be in a local occurrence of waters in which the H_2S had been oxidized to H_2SO_4 . A partial analysis of the silicified diorite runs as follows

	Per cent
SiO_2	70 30
Al_2O_3	20 00
MgO ,	0 31
CaO ,	0 27
K_2O ,	1 78
Na_2O ,	0 64

The large percentage of alumina indicates the presence of kaolinite, so commonly accompanying silicification. Sericite is also present.

A further instance of silicification in part, probably, due to cementation, is mentioned in the case of certain sedimentary rocks adjoining the vein. Here again it is accompanied by a development of pyrite, and the silicification extends to a distance of 15 feet from the vein.

The Treadwell Mine, Alaska.—According to G. F. Becker,† the country-rock of the celebrated Treadwell mine consists of a sodium syenite, which is strongly altered and traversed by small seams, carrying a value chiefly in gold. The whole mass of seams and country-rock is mined and milled. The process of alteration consists in a change of the albite, which is the predominant mineral, into carbonates and pyrite. Sericite is also present, as well as a little chlorite.

Gold-Veins of Ontario, Canada.—Peter McKellar‡ describes quartz-veins in granite of Western Ontario at Lake of the Woods, which are supposed to be of Archean age. The quartz-veins are only from 3 to 4 in. wide containing auriferous sulphides of copper, lead, zinc and bismuth. These narrow veins are adjoined by from 2 to 5 ft. of altered granite, largely consisting of a greenish fine-grained mineral, probably sericite. Some of this altered granite contains gold, and from 0.5 to 3 per cent of auriferous pyrite, while the above mentioned sulphides rarely appear in it. The principal ore consists of this altered rock.

Schwarzwald Fissure-Veins.—Much material of interest relating to the alteration of country-rock is found in the well-known

Including Fe_2O_3 , TiO_2 , and P_2O_5

† 18th Annual Report U S Geol Surv, part iii, p. 64

‡ Trans., xxix, 104 (1899)

investigations of Prof. Sandberger.⁺ In his discussions, as may be expected, superficial weathering is not always strictly separated from deep-seated alteration. In the fissure-veins of Schapbach, in the Schwarzwald, biotite of the granitic country-rock yields a chlorite rich in iron and a substance supposed to be pélite. The decomposition (alteration?) of the gneiss in the same districts yields a mineral which Sandberger calls hygrophilite, derived from the alteration of oligoclase. It has a specific gravity of 2.70, and is closely allied to muscovite, if not identical with it. The alteration of the schistose gneiss near the veins, involving a formation of hygrophilite from oligoclase, shows a concentration of K_2O and a decrease of Na_2O . In one instance a conversion to carbonates was also noted. For a certain distance on both sides of the veins the rock is softened and altered. The extent of this alteration, which is supposed to be favorable to the occurrence of rich ore-bodies, corresponds to the extent over which its principal leaching has taken place. Sandberger thus derives the minerals of his veins directly from the adjoining country-rock. He further says.[†]

"It is of the greatest importance for the understanding of the veins occurring in this granite area to examine the alterations which the rock has suffered by means of waters containing carbonic acid, and by means of weathering with free access of atmospheric oxygen."

In the silver-veins of Wittich, Schwarzwald, Prof. Sandberger finds that the alteration of the biotite is accompanied by the separation of TiO_2 as anatase or brookite. The oligoclase is transformed to a kind of pinitoid which Sandberger calls lepidomorphite, and which may simply be an impure and microcrystalline muscovite. Two analyses are given of fresh and altered granite, the latter occurring close to a vein. The composition of the altered rock is almost the same as that of the fresh, except that a little iron, somewhat over one per cent. of lime, and an equal amount of magnesia, have been carried away. The potash remains practically constant, while about one-half per cent. of soda has been lost. The silica has suffered an increase of 2.5 per cent., the alumina of 1 per cent. Sandberger remarks with good reason that these slight changes

* *Untersuchungen über Erzgänge*, i. and ii

† *Op. cit.*, ii, p. 343

‡ *Op. cit.*, ii., p. 347

could very well have been effected by waters containing a little carbon dioxide.

Near the vein of Wittichen the ore-minerals are not confined to the fissure, but are also present to a remarkable extent in the altered rock adjoining it. The gangue is here quartz, barite, calcite and fluorite. The ores consist of native silver and various cobalt-minerals. The ore-minerals mentioned, accompanied by small crystals of chalcopyrite, occur abundantly in the altered granite. The veins traverse not only the granite but also the overlying Permian formation, although in these horizontal rocks they lose their mineral contents almost completely. They are rich only in the altered granite, the oligoclase and mica of which have been completely, and the orthoclase partially altered. It is acknowledged that these veins were formed when 1500 feet of rocks rested on the granite, and that consequently the temperature and pressure must have been higher than at the surface. In conformity with Prof. Sandberger's well-known views, the sulphides occurring on the veins are explained by reduction of sulphates.

The veins of Schapbach may be compared with those described from the Central Plateau of France by Daubrée. The similarity in occurrence, gangue and ores is very striking; only, in the case of the latter we have undoubted proof of their intimate connection with actual ascending springs.

9. *Silice and Calcitic Cinnabar-Veins.*

The quicksilver-deposits of the Pacific Coast have been described by G. F. Becker.* The cinnabar occurs chiefly in zones of fracture or in fissure-veins, and is almost always associated with quartz and chalcedonic aggregates. Opal is very commonly present in the ores, but the sulphide of mercury is very rarely if ever directly imbedded in it. The main deposit of opal preceded that of cinnabar and quartz.

Various rocks, such as diabase, diorite and serpentine, are adjacent to the quicksilver-veins. These rocks are nearly always more or less altered and converted into dolomitic carbonates. Many of them are also silicified, being converted into opal. Serpentine especially is often transformed in this man-

* Monograph XIII, *U S Geol Surv*

ner, and all transitions between the fresh rock and the pure opal may be found; the latter may retain the color and structure of serpentine. Certain glaucophanes from the Lake Quicksilver mine are altered into microcrystalline quartz. Although Mr. Becker recognizes the fact that the country-rock has been altered by carbonization and silicification, he insists that the cinnabar has been exclusively deposited in open spaces, and does not appear as a product of direct replacement of the wall-rock. The quicksilver-deposits are of special interest, because their intimate connection with ascending alkaline waters has been proved. These waters contain but little free carbon dioxide, earthy carbonates and earthy sulphates, but considerable sodic bicarbonate and sodic chloride, and some hydrogen sulphide.

10. *Sericitic Copper-Silver Veins.*

The copper-veins of Butte, Montana, which have been described by Emmons, Weed and Tower,* form an excellent illustration of this class and, according to Mr. Emmons, are typical replacement-veins. The deposits appear along well-defined fissures in granitic rocks; the principal gangue-mineral is quartz, the primary ores are pyrite, chalcopyrite, zinc-blende and galena. Bornite, chalcocite and covellite are regarded as sulphides formed later under secondary influences. In the vicinity of the veins the country-rock is impregnated with vein-material, generally pyrite and quartz. An impregnation of enargite has also been observed. Sericite and, later, kaolin have also been developed in the rock. The extent of the altered zone is generally proportional to the size of the ore-bodies, and may extend to a distance of 100 feet from the vein. According to the proportion of copper in such an altered mass it may constitute pay-ore or be considered as barren material

11. *Silicic and Dolomitic Silver-Lead Veins.*

The association of silver-lead deposits with limestone and other calcareous sedimentary rocks is a well-known fact, occurring again and again in all parts of the world. Very many of these deposits are not fissure-veins, or connected with such. But even among those genetically related to fissures, the ores

* Folio 38, *U S Geol Surv*

seldom form well-defined tabular masses, but occur mostly as irregular bodies, while the ducts through which the solutions found access have received but scanty deposits of ore. This is due to the great tendency of galena and zinc-blende, which in these deposits form the principal ore-minerals, to replace the limestone. Beyond doubt such a replacement very often occurs. It was convincingly established by Mr. Emmons in Leadville, Colo., and by Mr. Curtis in Eureka, Nev. In both these cases the demonstration was furnished by the study of structural relations, without the aid of microscopic examination. Indeed, the latter was scarcely possible, since in both these mining districts operations were still in the zone of oxidation, which obscured the relations of primary ore-minerals to the limestone. Since these reports were published, the conditions governing the replacement of the galena have not been greatly elucidated, except in Spurr's study of the Aspen district. The chemical reactions involved were, and are yet, in some doubt, the principal question being whether the galena was reduced from solution of sulphate of lead or deposited from sulphide solution (see p. 617). The microscopic study of the attending phenomena must help to settle this point.

The ores are accompanied either by a gangue of jasperoid, cherty rocks chiefly composed of silica, or by different carbonates, such as calcite, dolomite or siderite. (Those accompanied by a siderite gangue will be treated as a separate class.) Sericitic minerals are absent. The gangue-minerals mentioned have also very largely replaced the limestone.

In the Elkhorn mine, Mont., studied by W. H. Weed,* bodies of galena appear in a crystalline limestone and are directly connected with a fissure-vein. The beginnings of replacement are shown in specks of intergrown galena and pyrite, scattered through the rock, and always accompanied by small crystals of secondary quartz. The larger grains of galena are surrounded by a narrow rim of pyrite (see page 617 and Fig 29).

Mr. Emmons describes the fissure-vein of the Queen of the West mine, Ten Mile district,† Colorado. The principal fissure is partly filled with barren calcite, while galena and blende re-

* Unpublished notes† Folio 48, *U S Geol Surv*

place the country-rock, consisting of sandstone and intercalated sheets of porphyry. The vein is characterized, besides, by a number of parallel fault-planes, from which replacement has taken place.

Aspen, Colorado.—Mr. Spurr, in his description of the Aspen district,* with its wonderfully complicated system of faults, has given a valuable description of the metasomatic processes there observed. The Aspen deposits are not, strictly speaking, fissure-veins. The ores form irregular bodies of lead- and silver-minerals in limestone; but these irregular bodies are closely connected, genetically, with faults which yielded a pathway for the ascending waters. The processes consist in dolomitization, ferration, silicification, and lastly, the introduction of metallic sulphides. The ores occur in part as filling of pre-existing cavities, but more generally replace the limestone adjoining the fissures. The dolomitization which proceeds irregularly from the fissures is well shown under the microscope, the coarse calcite being broken up into smaller rhombohedral crystals of the yellowish tinge characteristic of dolomite. Silicification usually accompanies dolomitization. In the limestones the process goes on in the following manner. Many tiny quartz-grains first appear scattered through the rock, chiefly along areas of slight shearing or fracture (Fig. 3). Here and there appear long slender quartz crystals, entirely surrounded by fresh limestone. As silicification proceeds, the slender crystals multiply, forming a characteristic network, sometimes enclosing small areas of calcite which are sprinkled with small, irregular quartz-grains, down to the most minute dimensions. The final result is a rock made up of crystalline quartz-grains of varying size, in which the retiform structure is still apparent (Fig. 4), and which rock resembles a chert or a fine-grained and altered quartzite, and is generally somewhat porous, drusy, and also often colored red or yellow. In structure, appearance and origin, this cherty rock is identical with the jaspers of Lake Superior. Mr. Spurr proposes "jasperoid" as a term for this rock, consisting essentially of cryptocrystalline, chalcedonic or phanero-crystalline silica formed by the replacement of other rocks, chiefly limestone. At Aspen this jasperoid forms big reefs along fault-lines.

* J. E. Spurr, Monograph XXXI, *U. S. Geol. Surv.*

Dolomitization and silicification are always accompanied by a certain amount of ferration. Usually the iron appears in the partly silicified rocks as small rhombohedrons of siderite; but pyrite is also present, and in many cases the two minerals have been deposited simultaneously.

In the final process of mineralization, the altered limestone is always traversed by reticulated fractures. In every case the ores are first introduced along these crevices, and often this is the only method of mineralization. With greater alteration, metallic minerals penetrated from the fractures into the rock on both sides. The solutions traveled between adjacent crystals of calcite or dolomite, and also along the cleavage-planes of these minerals. In this manner a still finer network was formed, which, by spreading and consolidation, resulted in a continuous mass of sulphides. There is no doubt, Mr. Spurr says, that this is an actual process of replacement; the calcite or dolomite being taken up, molecule by molecule, and replaced by metallic minerals. The sulphides are often accompanied by granular quartz and dolomite, the relations of which show that they have been simultaneously deposited.

12 *Sideritic Silver-Lead Veins*

In this class, which, like the preceding, ordinarily occurs in sedimentary rocks, not much secondary silica is formed. The principal gangue-mineral is siderite, often accompanied by other carbonates, and nearly always also with some pyrite; in fact the co-existence of pyrite (often also marcasite) and siderite is a notable feature. The other principal ores are galena and zinc-blende. The Eureka, Nev., deposits probably belong to this type.

Wood River, Idaho.—Prominent representatives of this class are the Wood river silver-lead veins, near Hailey, Idaho,* which occur chiefly in calcareous carboniferous shale, and are of pre-Miocene age. In the structure of the vein and arrangement of the ore-bodies replacement is clearly indicated, and galena often occurs as scattered grains throughout the shale. But some filling of pre-existing cavities has also taken place.

The rocks clearly contain much organic material; and the theory of deposition by the reduction of lead sulphate is pos-

* W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, part III, pp. 190 to 231

sibly applicable. But this argument is greatly weakened by the occurrence of veins of the same composition in a neighboring body of granite.

Cœur d'Alene Mountains, Idaho.—There exist, perhaps, no better instances of metasomatic fissure-veins than the celebrated silver-lead deposits of the Cœur d'Alene mountains, in Northern Idaho. They are clearly defined fissure-veins cutting fine-grained greenish quartzites and quartzitic slates of doubtful (though probably Algonkian) age. The principal ores are galena and zinc-blende, but there is also much finely distributed pyrite. Chalcopyrite is ordinarily absent. These are practically the only metallic minerals, and recur in all the deposits. The principal gangue-mineral is siderite, accompanied by minor quantities of quartz and barite. Fluorite is absent. The fissures along which the ore-bodies appear are well defined, and sometimes continuous for one or more miles. The ore-bodies do not show much clearly defined crustification or other evidence of having been deposited in open spaces. The siderite appears always as an undoubted product of replacement, while many veinlets of quartz have in part resulted from the filling of open small fissures. Evidences of gradual transitions from ore to country-rock are abundant, and are especially prominent in the mines carrying low-grade ore, as, for instance, in the Helena and Frisco. In the exposures underground, as well as in the specimens and thin sections, the evidence of replacement is complete and positive.

The greenish-grey fine-grained quartzite, which constitutes the prevailing country-rock, contains no sulphides when fresh. It is composed of small, rounded, or subangular quartz grains, closely packed—often, indeed, jointing closely, as in a normal quartzite. Usually, however, a little sericite, in bunches of small fibers, is present as cementing material between the grains. This sericite is apparently an autogenetic mineral, formed during the metamorphism of the sandstone to a quartzite. Occasionally small foils of it project into the quartz, showing a slight incipient sericitization of the latter mineral. There are few other minerals, except a little feldspar in clastic grains, small prisms of tourmaline, and some grains of calcite. Near the veins minute specks of siderite, zinc-blende, pyrite and galena appear in this quartzite; and these scattered grains

gradually merge into bodies containing 3 per cent. and more of galena, thus forming a merchantable ore. The thin sections show how the rock near the veins is filled with small grains of branching and irregular form, which consist of siderite, developed by attack first upon the ground-mass and then upon the grains of clastic quartz. This process is well shown in Fig. 16, which is reproduced from a thin section of Helena and Frisco country-rock. Accompanying the siderite are small grains of zinc-blende, cubes of pyrite and irregular wiry masses of galena. All these sulphides appear not only in or near the siderite, but also in the cementing sericite, and in the apparently perfectly fresh quartz grains.

At a more advanced stage (Fig. 17) these areas of siderite extend until they join, and thus completely replace the rock. In the specimen from which Fig. 17 was taken, masses of siderite are seen to be merging gradually into the fresh quartzite. In the resulting ore lie scattered many small quartz grains, representing remnants of the clastic constituents of the quartzite. Occasionally larger masses of zinc-blende appear to form directly in the quartzite by metasomatic replacement of the quartz. The sericite in the quartz then disappears, though once in a while small foils of it may be detected. During the transition stage, seams and narrow veinlets in the altering rock are filled with sericite, apparently segregated there, when driven out from the main mass. In other specimens from the Helena and Frisco mine, the replacing siderite has a strong tendency to idiomorphic development. Imperfect rhombohedral forms are often seen, sometimes cutting straight across the clastic grains (Fig. 18). Certain specimens from the Bunker Hill and Sullivan mine show quartzose greyish masses of irregular outline, and apparently merging gradually into the normal greenish quartzite. These quartzose masses consist of very irregular interlocking grains of quartz, not in the least similar to the quartz usually deposited by processes of filling, but having every appearance of resulting from the silicification of the quartzite. This silicified portion contains irregular grains of pyrite, galena and brown zinc-blende, with a very little siderite.

The process, as outlined, is remarkable, as involving a metasomatic replacement of quartz by siderite, pyrite, galena and zinc-blende, and is the only clearly defined occurrence of this kind of which I am aware.

This description would not be complete without mention of certain interesting veinlets produced by replacement in the Bunker Hill and Sullivan quartzite. Certain specimens from this mine show a dark greyish-green, very fine-grained quartzite, traversed by minute veinlets, carrying quartz and surrounded by a greenish material. Under the microscope the rock is seen to be a typical fine-grained quartzite or quartzitic sandstone. The grains are separated, not only by fibers of muscovite, but also by a green mica, probably related to biotite. The veinlets are clearly formed by replacement along narrow cracks, and contain a mass of green mica in fine distribution, diminishing away from the seam, together with quartz, garnet, brown zinc-blende, and small prisms of tourmaline, and a small quantity of galena. I have mentioned these peculiar products of replacement because they differ so completely from the deposits as described above. Their formation must be sought in some local cause, involving a change in the mineral-bearing solutions, or in the conditions of the deposition. The presence of garnet in these veinlets is especially remarkable, as this mineral rarely occurs in fissure-veins.

13 *Sericitic Lead-Silver Veins*

The Clausthal Veins—The alterations produced in the clay slates adjoining the vein-system of Clausthal have been described by v. Groddeck.* The fissure-veins at Clausthal, which principally carry galena, pyrite and zinc-blende in quartzose gangue, are enclosed in black clay slate belonging to the Culm formation; and to the eye these slates, when enclosed in the vein or lying close to it, ordinarily present no alteration, except such as may result from mechanical deformation or crushing. By a series of analyses, v. Groddeck has shown that, as a matter of fact, these wall-rocks have suffered alteration considerable in degree, although not apparent to the eye. Some average analyses are given in Table VI.

Comparing the first two analyses, it is apparent that a large part of the protoxide of iron has been carried away, and that at the same time the magnesia has been considerably reduced. These subtractions result in an apparent increase of the other

* "Studien über Thonschiefer, Gangthonschiefer und Sericitschiefer." *Jahrbuch der königl. preuss. geol. Landesanstalt*, 1885, pp. 1 to 53.

TABLE VI.—*Analyses of Clausthal Rocks.*

	I	II	III
	Per cent	Per cent	Per cent
SiO ₂	56.59	59.31	79.12
Al ₂ O ₃	23.14	23.72	13.93
Fe ₂ O ₃	61	1.13	44
FeO	4.87	1.06	
MnO			
MgO	1.80	1.11	
CaO	.35	.36	
K ₂ O	3.05	3.91	3.18
Na ₂ O	75	80	64
H ₂ O	4.01	4.60	1.56
Rutile	38	23	not dt
Carbon	64	95	not dt
Pyrite	67	85	not dt
Apatite	14		not dt
Carbonates	2.56	2.02	1.60

I Black normal clay slate of the Culm formation Average of three analyses —II Black clay slate adjoining the vein or enclosed in it Average of seven analyses These black altered clay slates are always present in or along the veins —III Variegated clay slate adjoining the vein Average of four analyses These variegated slates are apparently extreme forms of alteration, and are conspicuous by means of their red or yellow color It is remarked, however, that this form of alteration is an unusual one, only appearing locally in a few mines The processes to which these altered rocks have been subjected are considered to have been different in kind from those producing the ordinary black altered slates

constituents. Very notable is the fact that the alkalis remain nearly constant, and that no soda has been subtracted—a most unusual case. The lime, rutile, carbon, pyrite and carbonate have suffered but little change The amount of alumina is almost identical in the two analyses, and on the assumption that this constituent has remained constant, the two analyses can be directly compared

Comparing the first with the third, a very strong increase in silica and decrease in alumina is noted, accompanied by an almost complete disappearance of the protoxide of iron, magnesia and lime, the alkali apparently remaining practically constant. It is clear that the alumina has been carried away to a considerable extent, and the process is, on the whole, similar to the alteration which results from the action of the solutions containing free sulphuric acid on aluminous rocks. Sericite and chlorite form part of the fresh rock, and the former is a prominent constituent of the altered rocks Basing the calculations on the following formulæ:

Sericite, $2\text{H}_2\text{O} + (\text{K}_2 \text{Na}_2 \text{Ca}) \text{O} + 3 (\text{Fe Al})_2 \text{O}_3 + 6\text{SiO}_2$,
and

Chlorite, $4\text{H}_2\text{O} + 5 (\text{Mg Fe}) \text{O} + \text{Al}_2 \text{O}_3 + 3\text{SiO}_2$,

and disregarding the small amounts of carbonate, pyrite, etc., the following results are obtained.

	Fresh clay slate.	Vein clay slate	Variegated clay slate
	Per cent	Per cent	Per cent
Sericite,	39.24	47.45	34.89
Chlorite,	16.54	4.37	. .
Quartz,	35.80	34.40	63.24

These are the averages of the calculations of all the analyses. The character of the alteration is thus clearly seen to consist in a chemical change of the chlorite into sericite, with simultaneous subtraction of FeO and MgO. The quartz is practically constant.

In the case of the variegated clay slates, the change appears to be of a different kind. A comparison of the third column with the first shows that the following reactions have taken place. 1. The chlorite has been completely destroyed; its bases have been carried away, and its silica has probably been added to the free quartz. 2. The percentage of sericite has been diminished (more, in fact, than the 4 per cent shown by the comparison of the calculations, since we must consider the amount of the bases carried away). 3. The percentage of quartz has been increased by the introduction of free silica besides that obtained from the alteration of the sericite and the chlorite. It must again be emphasized that this process points to the action of a solvent, probably sulphuric acid, capable of carrying away considerable amounts of alumina.

The Democrat Vein, Harley, Idaho.—The Carboniferous strata near Wood river, Idaho, contain masses of intrusive granite, or, as more specifically determined, quartz-monzonite.* This rock is cut by fissure-veins containing galena, sphalerite and tetrahedrite, with siderite and calcite gangue; the ore being due, partly, to filling of open fissures, partly to replacement. For a few feet on each side of the vein, the granite is altered and contains some pyrite, galena and zinc-blende. The altered rock is of greyish-green color and its texture unmistakably indicates its derivation. The biotite of the granite is converted

* W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, part iii, pp. 206 and 212

to large foils of muscovite; the feldspars are also completely changed to radial tufts and scaly aggregates of sericite, mixed with calcite grains. The quartz grains are in places vigorously attacked by sericitization and carbonatization, in the manner illustrated in Fig 13. The apatite is completely unaltered, and the titanite is converted to bunches of rutile needles. A little chlorite remains. For complete analyses and calculations, the reader is referred to the report cited. The altered rock consists of. Quartz, 55.07; sericite, 31.78; chlorite, 7.21; calcite, 4.39; siderite, 0.05; rutile, 0.40, apatite, 0.23; pyrite, 0.19, pyrrhotite, 0.07, zinc-blende, 0.14; water (hygroscopic), 0.37; total, 99.90 per cent.

From the determination of specific gravity it is concluded that no change of volume has taken place, but the granite has altered to an aggregate of denser minerals, the result being a rock of considerable porosity. On this basis, namely, the comparison of equal volumes, the following changes, expressed in kilograms per cubic meter, have taken place

TABLE VII — *Gains and Losses of Country-Rock of the Democrat Vein, Idaho, During Alteration.*

	GAIN		Loss	
	Per Cubic Meter of Original Rock	Percentage of, for Each Constituent	Per Cubic Meter of Original Rock	Percentage of, for Each Constituent
	Kilos	Per cent	Kilos	Per cent
SiO ₂			49	2.7
TiO ₂			3	2.3
Al ₂ O ₃			99	24.7
Fe ₂ O ₃			10	61.6
FeO	22	42.3		
MnO	3	150.0		
CaO			6	8.5
SrO			1	100.0
BaO			3	100.0
MgO			18	56.2
K ₂ O			33	29.0
Na ₂ O			80	93.0
H ₂ O below 105° C . .			5	35.8
H ₂ O above 105° C .	31	155.0		
P ₂ O ₅			1	25.0
CO ₂	43	nearly all		
S	4	nearly all		
Fe	3	all		
Co, Ni				
Zn	2	all.		
	108		308	

The result shows a total loss of substance of 200 kilograms per cubic meter. The losses extend over all the bases and the silica, baryta and strontia being completely removed without the appearance of barite in the vein. The gains chiefly consist in water, carbon dioxide, ferrous oxide, sulphur and zinc. Both potash and soda are removed, the former only partially, the latter almost completely. Calculated without regard to porosity, by comparing equal weights, the result is reached that the rock has received an addition of substance; but the manner here indicated is doubtless the correct way of regarding the process.

14. *Zeolitic Copper-Veins*

The copper-deposits of Michigan are in part fissure-veins cutting across the beds of melaphyre and other basic igneous rocks so common in that district. It is true, however, that the ore-bodies of the large mines are not to be considered as fissure-veins, but rather as beds or strata along which copper has been deposited by a process of replacement. R. Pumpelly* investigated the copper-deposits of Michigan and published part of his results in 1873. Further contributions to the same subject are found in his celebrated paper on "The Metasomatic Development of the Copper-Bearing Rocks of Lake Superior."† In these investigations the theory of metasomatic replacement was applied to American ore-deposits, and in this field Prof. Pumpelly is clearly the pioneer in this country. The copper-bearing veins contain a number of minerals not ordinarily present in fissure-veins, and are, therefore, of special interest. Among these minerals are the zeolites, laumontite, apophyllite and analcite. There are also present as gangue minerals, prehnite, datolite, chlorite, delessite, calcite, orthoclase and quartz. The principal ore-mineral is, of course, the native copper. Of sulphides, chalcocite and bornite are sometimes, but very rarely, encountered.

According to Pumpelly's description, the veins must be due in part to filling; but very largely, perhaps predominantly, the ore results from metasomatic replacement. The stages of this alteration Prof. Pumpelly considers to have been . 1. A forma-

* *Geol. Surv. of Mich.*, vol. 1, part ii.

† *Proc. Am. Acad. of Arts and Sciences*, vol. xiii., 1877-78, p. 253

tion of chlorite in the amygdaloid rock, 2 Individualization of non-alkaline silicates, such as laumontite, prehnite and epidote, 3. Deposition of quartz, 4. Introduction of native copper, accompanying which there was a replacement of prehnite by a green earth or delessite, often intimately connected with the copper, 5. Appearance of the alkaline silicates, such as apophyllite, orthoclase and analcite.

This occurrence of secondary orthoclase or adularia is of special interest in view of the fact that the same mineral has lately been found to form an important gangue-constituent in certain Tertiary fissure-veins in volcanic rocks of the West. It is considered that the alkaline silicates represent the final stage, namely, the decomposition of the labradorite of the original rock, while the chloritization represented the first stage of alteration, namely, that of ferro-magnesian silicates to chlorite. Prof. Pumpelly thinks that copper was originally present as sulphides in the rocks, and that the changes, consisting in leaching and re-disposition in veins, have been effected by surface-waters carrying carbonic acid and some atmospheric oxygen. The copper was deposited after the destruction of the ferro-magnesian minerals, and before the deposition of the products from the decomposition of the feldspars. From the state of sulphide, copper was converted to silicate, carbonate and sulphate. These salts were then reduced to a metallic state. He thinks also that there is a close genetic relation between this metallic copper and the ferric condition of the iron oxide in the associated silicates. The oxidation of the iron was caused by the reduction of the oxide of copper at the expense of the oxygen of the latter.

Prof. R. D. Irving, in his report on "The Copper-Bearing Rocks of Lake Superior,"* confirms in general the conclusions of Prof. Pumpelly. He considers the veins as very largely replacement-veins not sharply defined from the surrounding rocks, but simply the result of a rock-alteration entirely analogous to that which has brought about the deposition of copper and its associated vein-stone minerals within the cupriferous amygdaloids. They are alteration-zones, which traverse instead of follow the bedding. The replacement of wall-rock by cop-

* Monograph V, *U S Geol Surv*, 1883

per masses is a common occurrence; and the paragenesis of the vein-minerals is identical with that of the copper-bearing amygdaloid rocks

Especially remarkable is the series of replacements which, as shown by Pumpelly, has taken place in these veins. Prehnite is pseudomorphic after plagioclase; and many amygdaloids are largely prehnitized. This prehnite is again replaced by orthoclase; and finally, the latter may change into epidote and quartz. Sericite is absent.

These copper-bearing veins are clearly very different from the majority of fissure-veins, and have been formed under very different conditions—in fact, probably not by thermal waters. Of other classes, the orthoclase-albite-zeolite veins of the Alps are most closely related, while a certain slight resemblance also exists to the propylitic veins, emphasized by the chloritic alteration and the presence of orthoclase

The veins of Kongsberg, Norway, and Andreasberg in the Hartz mountains, both of which also carry zeolites, are not sufficiently known in their metasomatic aspects to be discussed here.

Observed Alteration by Ascending Waters.

Extremely little exact work has been done in this most important line of investigation, namely, to ascertain actual alterations by waters of known composition. In veins we usually have only the altered rock as a known quantity, and must endeavor to draw conclusions from this as to the character of the waters.

Most interesting and well known is Prof. Daubrée's discovery of the alteration which the old Roman bricks and mortars have suffered at the place where the mineral springs of Plombières break through the granite, ascending on fissures carrying fluorite and quartz. The waters are thermal, having a temperature of 70° C., and may be characterized as weak mineral waters, containing sulphates and chlorides, with a little hydrogen sulphide, silicates of potash and soda are also present in them. In the bricks employed by the Romans as curbing for the spring, a number of minerals have been deposited. Chief among them are the zeolites. Chabazite, mesotype, and apophyllite are the principal minerals formed in the pores and spaces of dissolution in the old bricks. Besides

these, opal and chalcedony have been deposited; and, on one piece of mortar, fluorite, scalenohedrons of calcite, and prisms of aragonite were also found. This is extremely interesting, as the fissures on which the spring rises contain much fluorite. The apophyllite also was found to contain a notable percentage of fluorine. An analysis of this altered brick gave the following result: SiO_2 , 19.39, Al_2O_3 , 17.33, Fe_2O_3 , 5.37, CaO , 51.40; MgO , 0.75, K_2O , 5.94, Na_2O , 0.33; total, 100.51 per cent.

In this analysis the most remarkable fact is the strong prevalence of potash and the small quantity of soda present. It is scarcely to be assumed that the ordinary bricks of that locality contained the alkalis in this proportion. The porous bricks were evidently specially adapted for the formation of new minerals, and the large percentage of lime in the mortar also facilitated the process. Daubrée mentions that pieces of granite enclosed in the same mass show no zeolitization, and refers at the same time to the fact that pyroxene and feldspar show no alteration in the same superheated glass tubes in which glass is completely transformed into zeolites and into silica. This shows in a striking manner the dependence of the alteration of the country-rock upon its structure and composition.

Mr. W. H. Weed has recently* found a mineral vein in process of formation by a weak thermal water at Boulder, Montana. The vein-filling consists of quartz, calcite and some stilbite, while the adjoining granite is partly altered to sericite and kaolinite; these two minerals attacking all of the primary constituents (Fig. 19). A little free silica is also mixed with the kaolinite. In some specimens the kaolinite and sericite are subordinate and the feldspar appears partly silicified.

CONCLUSIONS.

Some of the following conclusions, drawn from the data presented in this paper, may seem trite repetitions of already known facts; but it is perhaps well to remember that our knowledge of the genesis of mineral deposits is not built on such firm foundations that it does not need fortification of its position by conclusions from all possible view-points

1. Almost all fissure-veins are bordered by altered zones of

* Communicated to me from an unpublished paper.

varying extent and intensity of alteration. In the so-called "replacement-veins" this altered and replaced rock contains the valuable ore.

2. The metasomatic processes in different classes of veins show an almost kaleidoscopic variety. In one class of veins, quartz may be converted into calcite, while in a different class calcite may be converted into quartz. The action is usually intense, involving a great change in the chemical composition.

3. The hydration connected with the alteration is only very moderate.

4. The most prominent mineral formed by the metasomatic processes is a potassium mica (muscovite, sericite, zinnwaldite and many other related species). The most prominent process is the progressive elimination of soda and concentration of potash, closely connected with the formation of potassium mica.

5. The metasomatic processes in fissure-veins differ distinctly in most cases from those involved in ordinary static, dynamic and contact metamorphism, and the two classes of change have not generally taken place under the influence of the same conditions and agencies. Greisen is only found near cassiterite-veins. Granite, thoroughly changed to sericite, calcite and pyrite, is never found as a result of any other metamorphism than in fissure-veins, nor are fluoritized or sideritized rocks so found. The propylitic and biotitic alteration, the chloritic and zeolitic alteration of Lake Superior copper-veins, and the silicification in limestone and other rocks form exceptions, being similar to certain developments of dynamic, static and hydrochemic metamorphism.

6. Ordinarily, the alteration consists in the total or partial loss of certain constituents; the gain of others; and the introduction of new compounds and elements, usually carbon dioxide and sulphur. The net total of the change per unit of weight or volume may be a gain or a loss, perhaps more often the former. If sulphides are abundantly introduced, the result will usually show a strong gain in mass.

7. The processes observed are such as can only be explained by aqueous agencies. Possible exceptions are the forms of alteration connected with cassiterite, apatite and tourmaline-veins, in which pneumatolytic conditions may have partly obtained.

8. The intensity of the processes observed indicates that the aqueous solutions acted under moderately high temperature, pressure and concentration. No cold, pure surface-water could produce such results as are ordinarily found.

9 From the fact that the substances introduced, such as sulphur, carbon-dioxide, fluorine, boron and heavy metals, are only known to be contained in noteworthy quantities in thermal waters ascending on fissures, it is concluded that these waters were the agencies usually active in the process of alteration.

10. Many of the substances found in the filling of the open spaces along the fissure may be lacking in the altered rock, showing that the latter forms a septum not penetrated with equal ease by all constituents of the solution.*

11 The ascending waters are chiefly surface-waters, which, after a circuitous underground route, have found in a fissure an easy path on which to return. During their long downward passage they doubtless dissolve much material from the rocks which they penetrate; and this solution was facilitated by the gradually increasing heat and pressure with increasing depth. During the ascending period, much of this material is deposited. The metasomatic action on the wall-rock results in further exchanges of constituents, some being dissolved and others deposited.

For many veins, this genetic theory may be fully sufficient. But for many others, perhaps for the majority of fissure-veins, something seems to be lacking in this explanation. The difference in the metasomatic processes in veins and in other forms of metamorphism must be taken into consideration, as well as the abundance of certain constituents, such as carbon dioxide and hydrogen sulphide, in mineral waters. The presence of these constituents has not been satisfactorily explained, and cannot be, except in certain cases, on the theory of solutions derived from the solid country-rock.

I believe that the majority of fissure-veins are genetically connected with bodies of intrusive rocks, even when the actual deposits are contained in the overlying surface lavas. It is well known that the intrusive rocks, such as granite, diorite

* The existence of such osmotic conditions was first suggested by G. F. Becker (*U. S. Geol Surv, Min Res*, 1892, "Quicksilver Ore-Deposits," p 159)

and gabbro, may contain at the time of their intrusion water, carbon dioxide, fluorine, boron and sulphur. Under decreasing pressure, these substances have a tendency to leave the cooling magma; and as many of them form, with the heavy metals also contained in the magma, volatile compounds with a low critical temperature, these heavy metals may be carried away from the magma along with the "mineralizing agents" mentioned above. This is the well-known theory which was originated by Elie de Beaumont and Daubrée, and developed by other French investigators; but until recently it has hardly received the attention which it deserves. The results of these emanations is shown in the contact metamorphism and in the mineral deposits often appearing near the boundaries of intrusive bodies. Where fissures traverse the cooling magmas, and the rocks surrounding them, it is natural that these mineralizing agents carrying their load of heavy metals should ascend, at first under pneumatolytic conditions, above the critical temperature. Reaching the zone of circulating atmospheric waters, it is natural that they should mix with these, which probably greatly predominated in quantity. To this combination of agencies, found in the ascending waters of such regions of igneous intrusion, the formation of most metalliferous veins is probably due. This dependence of veins on intrusive bodies is most clearly perceived in certain cassiterite-, apatite- and tourmaline-veins; but from these all sorts of transitions may be found, to veins of more ordinary character.

I am by no means prepared to deny that some classes of veins may be due to circulating surface-waters alone; but I do not believe that the dissolving power of the latter is sufficient to account for all classes, or even for the majority, of fissure-veins.

A Mining Survey.

BY J. F. WILKINSON, SAN FRANCISCO, CAL

(Canadian Meeting, August, 1900)

A HIGH degree of accuracy is often required in mine-surveying, in order that expensive mining work may not be misdirected. The making of underground connections by drifts or shafts located as the result of surveys presents a crucial test of correctness not usually involved in any other class of surveying. In view of these considerations, the present notes and description of a survey made in June, 1890, for the San Francisco shaft of the New Almaden quicksilver-mines, may be of interest to members of the Institute who are surveyors.

The purpose of this survey was to locate on the surface a vertical 2-compartment shaft (3.5 by 7 ft.), to connect with another vertical shaft, of practically the same size, which had been sunk a number of years before from an adit-level about 240 ft. vertically below the surface, to a deeper, so-called 600-ft. level. It will be seen, of course, that the most important matter was to secure an exact coincidence in vertical line, so that the resulting continuous vertical shaft from the surface should have no offset or irregularity at the point of junction between its two parts. The levels were of less importance, but, as the hoisting-works were to be placed in position and the new shaft permanently timbered from the start, its correct alignment was an essential requirement. The important features of the work, therefore, were the methods used in determining with certainty: 1. That the shaft was located in the right place in a general way; 2. That the ordinary inaccuracies of linear and angular measurements were so reduced as to insure correctness of location within certain defined and allowable limits.

Instruments.—The instruments used were a Buff and Berger transit-theodolite, with a 6-in. horizontal plate, reading to 10 seconds, a Heller and Brightly Y-level; a Chesterman steel tape, graduated in tenths and hundredths of a foot; and New York leveling-rods, graduated to thousandths of a foot.

The leveling-rods and tape were compared with a standard of measurement, and the correction for each was ascertained. In the case of the tape, the conditions for the standard were, that the pull should be 16 pounds, that the tape should lie horizontally on the ground, and that the temperature should be 70° Fahr. (this being the average temperature in the adit underground). Three corrections were thus actually necessary for each tape-measurement, viz.: to reduce to the standard; to correct for the catenary curve; and to correct for difference in temperature.

While the graduations on the tape were made to hundredths, yet, in careful measurements, it was possible to estimate thousandths of a foot, thus making these readings correspond in minuteness with those obtainable on the leveling-rods.

Of course, to do this underground, it was necessary to use very fine fish-cord for plumb-lines, and, on the surface, measurements were made between small headless wire nails in stakes previously aligned by means of the transit. Here the hypotenuse was thus obtained, while the vertical component was obtained by leveling; and from these the horizontal component was calculated in the usual manner. Underground measurements were made on a practically horizontal plane, by means of marks on plumb-lines previously aligned by the transit, and leveled.

To correct for the catenary curve, the weight of the tape per foot was ascertained, and the correction was calculated by the usual formula. For a tape weighing 0.00725 lb. per ft., with a pull of 16 lbs. (exerted in all measurements by means of spring-balances), the correction to be applied in 100 ft is 0.00855 ft., and in 50 ft. only .00107 ft.

For temperature, the correction in 100 ft. for a difference of 1° F. is 0.00069 ft. Most of the measurements in the adit were made at a temperature not varying appreciably from the assumed standard. On the surface, however, the temperature in some instances varied from the standard as much as 20° F.

In making the angular measurements, the greatest care was taken; and, by the most approved methods—repeating angles, reversing the telescope, reading both from right to left

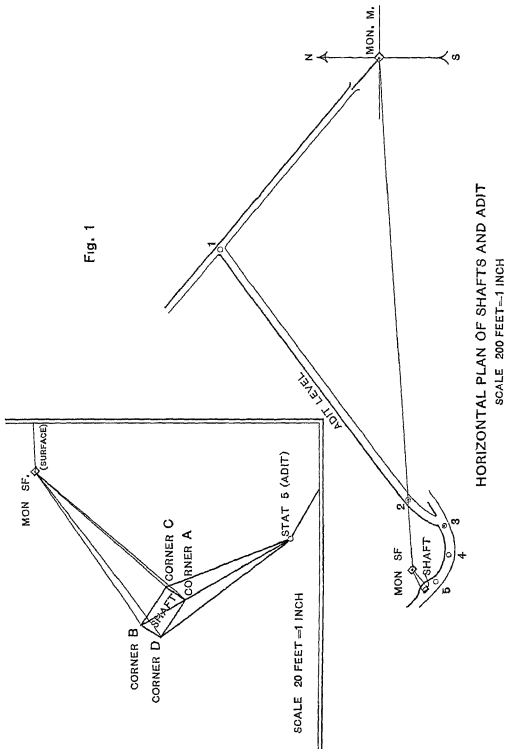
and from left to right, etc.,—all possible instrumental errors, unavoidable errors of adjustment, and personal errors of observation, were eliminated. All angles were read at least twice; and in some cases as many as four readings of ten repetitions each were taken. The number of times each angle was read, and the number of repetitions in each case, are shown in Column No. 4 of Tables I. and II. By the means thus employed, the angular measurements were made certainly correct within one second.

Preliminary Survey.—In the preliminary survey, the mean of two sets of tape-measurements was taken. For the surface-line, besides the tape-measurements, two sets of levels were also run. As to the surface-line (Monument M. to Monument S. F.), it may be observed that neither monument was visible from the other, so that, in order to define the line, several settings of the transit at intermediate points were necessary. The different measurements reduced, the calculations made, and the results obtained in this—the first complete—survey, are shown in Table I., and, for their better elucidation, a horizontal plan (Fig. 1) and a vertical section (Fig. 2) of the tunnel and shaft are also appended

The shaft was located by this survey, the notes having been carefully calculated and checked, use being made of Bruhn's tables of logarithms, also of the natural functions from tables by a different author, thus eliminating any possible error due to misprints or other causes.

Check-Survey.—As a further precaution, to satisfy the first condition imposed, and guard against the overlooking of any glaring error in the work, a second complete survey was made, a week or more after the first. This, while made as a separate independent survey, also served to eliminate any errors of the first survey which might have been due to faulty setting-up of the transit, inaccurate centering over the stations, or sighting at the wrong station. The angles being taken differently (all being interior angles, from which the deflection angle was obtained by subtracting from 180°), any such error would have become apparent. In determining the surface-line only one set of levels was run; but an entirely different set of intermediate stakes was used, thus eliminating the possibility of repeating an error in this part of the work.

In making the calculations, besides those shown in Table II., the additional precaution was taken, in the check-survey, of assuming one course as a meridian line (Monument M.—Monu-



ment S. F.) and co-ordinating the different stations with reference to Monument M. by courses thus obtained.

Table II. shows the results of the check-survey.

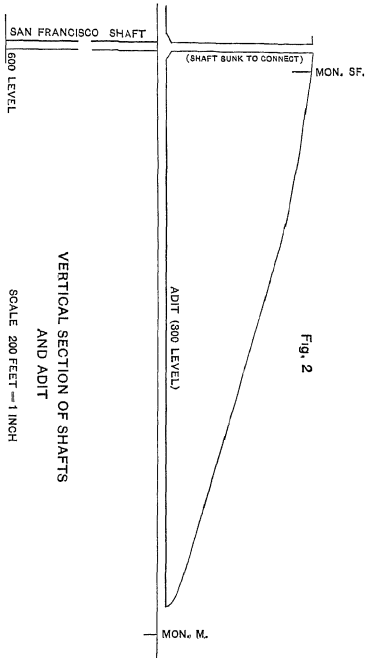
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TABLE II.—*Check-Survey.*

Station	Mean Deflection All Angles Being 180° minus Interior Angles	Calculated Bearing	Angular Measurements Number	Horizontal Distances, Corrected for Temperature and Catenary and Reduced to Standard				N	S	E	W	Co-ordinates	Station
			Of Obs	Of Rept	Obs 1	Obs 2	Mean					+N +W	
Mon M to Mon S F													
Mon M to 1	45° 5' 33" + IRt	S 86° 58' 57" W	4	10	403 074	403 076	403 076	270 102			290 190	000 000 000 Mon M	
1 to 2	74° 5' 05" Lt	N 47° 56' 30" W	2	10	587 205	587 207	587 206		311 256		299 190	270 102 299 190 1	
2 to 3	72° 23' 43" Lt	S 57° 59' 25" W	2	6					60 426		497 926	11 587 926 116 2	
3 to 4	54° 44' 31" Rt	S 59° 57' 40" W	2	6			67 000		44 808		28 944	101 680 826 060 3	
4 to 5	39° 50' 18" Rt	N 59° 49' 31" W	2	6			44 808		7 522		44 172	109 102 870 232 4	
5 to Cor b	31° 10' 47" Rt	N 59° 49' 31" W	2	6			41 070	20 648			36 565	88 459 905 787 5	
Mon M to Mon S F				3				23 911			13 061	64 648 918 788 Cor b	
Mon S F to Cor b	38° 39' 37" Lt	S 86° 58' 57" W	1				27 246		47 206		895 513	47 206 895 513 Mon S F	
							896 756		17 342		23 285	64 548 918 798 Cor b	
Test of Connection													
4 to 5		N 59° 49' 31" W											
5 to Wire Cor C ₁	39° 35' 25" Rt	N 20° 14' 06" W	1	2			21 507	20 180			7 439	68 279 913 176 Wire Cor C ₁ { Adj- level	
Mon M to Mon S F		S 86° 58' 57" W											
Mon M to Wire Cor C ₁	47° 5' 43" Lt	S 39° 53' 14" W	1	2			27 454		21 066		17 066	68 272 913 119 Wire Cor C ₁ { On sur- face	
									Difference			+0 007 +0 037	

✱

All results, however, indicated a certainty that the shaft was correctly located for all practical requirements, and to the strong probability that the corners of the shaft, as located on the surface, did not differ in coincidence from the corresponding corners on the adit-shaft by more than $\frac{3}{4}$ of an inch.



When the connection was made, no horizontal displacement in vertical alignment was detectable, but, to test the accuracy of the survey more closely, a fine steel wire, to which was attached an 18-pound plumb-bob, was suspended from the collar of the shaft to the adit below. A point was selected at approximately the position of the originally located corner, C

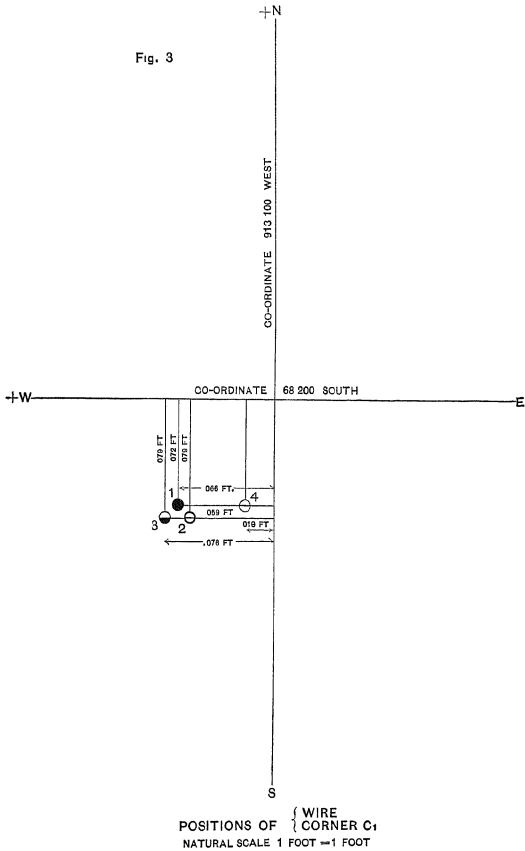
(called Wire Cor. C_1 in the notes). This was possible without fear of the wire touching the sides of the shaft, for the reason that the shaft had been made several inches wider and longer than the collar-set of the adit-shaft. To prevent oscillation, the plumb-bob was immersed in a mixture of molasses and water. Then, having ascertained that the wire hung freely without touching the sides of the shaft, or any other object, at any point, its position was instrumentally observed at both the surface and the adit-level. The co-ordinates thus obtained are shown in the tabulated notes. The difference between the two sets of co-ordinates is the error of the survey, and is shown in both the preliminary and the check-survey.

It must be said that the conditions under which the survey was made were most favorable for the surveyor. The two assistants employed were reliable and experienced in that class of work; and, as no mining was being done in that part of the mine at that time, there was neither tramming, blasting, powder-smoke nor changeable draughts to interfere with observations or distract attention. On the surface, the atmosphere was clear and the air steady; and, during the first part of the survey, there was very little wind. A sufficient length of time was allowed; so that nothing was slighted or overlooked on account of undue haste.

In summary review, the special features to be noted are. (1) the means taken to insure the location of the shaft in the right place (two independent surveys and check-calculations); (2) the methods used to reduce the ordinary inaccuracies of survey within allowable limits; and also the practical demonstration, here given, of the accurate results attainable by the use of the usual surveying-instruments and measuring apparatus, as described, when the most approved methods of observation are carried to the extreme, and neither time nor care is spared to make the results as nearly perfect as possible.

Fig. 3, drawn to natural scale, illustrates the final result of the surveys.

In this figure, the circle numbered 1, and completely filled with black, shows the position of Corner C_1 Wire, as co-ordinated from the adit-level by first survey; the open circle, No. 2, that of Corner C_1 Wire, as co-ordinated from the surface by first survey; the half-black circle, No. 3, that of Corner C_1 Wire, as co-ordinated from the adit-level by second survey;



and circle No. 4 (open, with a heavy horizontal diameter), that of Corner C₁ Wire, as co-ordinated from the surface by second survey.

By the location-survey the shaft was 0.007 ft. too far south, and 0.007 ft. too far east; by the check-survey, it was absolutely correct north and south, and 0.047 ft. too far east.

By averaging the two surveys, giving to the location-survey twice the importance or "weight" of the check-survey (because all of its measurements were made twice, while in the check-survey some were made only once), we have the average error of the survey; the shaft thus being 0.0047—ft. too far south, and 0.0203+ ft. too far east

This applies to the other three corners, as well as to Corner C.

Notes on the Occurrence of Platinum in North America.

BY DAVID T. DAY, WASHINGTON, D. C.

(Washington Meeting, February, 1900.)

In the summer of 1898, a demand suddenly arose for commercial quantities of the element osmium. At least half a ton was wanted for the manufacture of a new incandescent light. This led the writer to examine localities where platinum had been reported, in order to determine whether osmiridium was contained in the crude platinum. With the co-operation of the concern most interested, the Welsbach Light Company, and in company with its President, Col. William E. Barrows, I visited most of the leading American localities where platinum has been obtained. I also wrote to every available placer-mine in the West for samples of the heaviest sands, in order to test them for platinum. The results of this inquiry are given in the present paper.

Distribution.

The notices of the occurrence of platinum in this country given in scientific journals include two interesting observations in the East. One concerns a nugget described by Peter Collier of Washington, D. C.,* and said to have been found on land adjacent to the village of Plattsburgh, N. Y., which weighed 104.4 grammes, and contained sufficient chromite to reduce the specific gravity from 17.35 for the heaviest portion to

* *Am Jour Sci*, Third Series, vol. xxi., p. 123

10 446 for the average of the nugget. This nugget gave "unmistakable evidence of osmium."

Messrs. William E. Hadden and J H Pratt* have found sperrylite—platinum arsenide—in placers at several points in the Cowee valley of North Carolina. The conditions favor the belief that the source of this mineral is a ledge of impure rhodonite and biotite, containing much disseminated iron sulphides—conditions much like those at Sudbury, Canada

There have been unsubstantiated reports of the occurrence of platinum in place, in certain localities in the Catskills in New York, in granite near Philadelphia, and again near Port Deposit, Maryland, but the only localities where platinum is known to occur in North America, otherwise than as a mineral curiosity, are in California, Oregon and British Columbia.

As early as 1852, Prof. W. P. Blake† called attention to the existence of platinum at Port Orford on the Oregon coast, and noted that the platinum equalled from 10 to 30 per cent. of the gold. This article seems to be the original source of the statement that the proportion of platinum to gold increases northward. B. Silliman,‡ in his mineralogic notes on California, etc., extended our knowledge to the occurrence of platinum in the older deep placers, worked by the hydraulic process in Butte county. He also notes the occurrence of iridosmine with the platinum. Meanwhile T. Sterry Hunt had found platinum and iridosmine on the Riviere du Loup, Quebec, Canada, in 1851.

The various notes concerning the finding of platinum on the Pacific coast have been well summarized in the publications of the California State Mineralogist, and show that platinum has been found at many places on the Pacific beach, from as far south as San Bernardino county, northward to the mouth of the Columbia. Indefinite reports have been made of its occurrence further north on the Washington beach; but its amount is certainly not great. The principal beaches where platinum has been reported, beginning at the south, are Santa Barbara, Lompoc; the beaches of San Luis Obispo county, Santa Cruz; and occasionally between Santa Cruz and the Golden Gate. In accordance with Blake's statement, the richest beaches are fur-

* *Am. Jour. Sci.*, Fourth Series, vol vi, pp. 381 and 467

† *Am. Jour. Sci.*, Second Series, vol. xviii, p 156

‡ *Am. Jour. Sci.*, Third Series, vol vi, p 132

ther north, in Humboldt and Del Norte counties. The beach-mines of Gold Bluff, north of Arcata, Big Lagoon, Stone Lagoon, Little River, Crescent City, Cal., and Gold Beach and Port Orford, in Curry county, Oregon, have all yielded platinum in commercially appreciable quantities. Still further north, platinum is found at Yaquina Beach, Oregon; but the sands there are poor. Port Orford has proved, perhaps, the richest beach.

Sharpless and Winchell have made an unusually careful examination of the sands at Bandon, on the Oregon beach. They almost invariably found platinum; but the proportion was not so encouraging as less careful workers had estimated. All this beach-platinum is discouragingly fine and difficult to save.

Most of the platinum-product has come from inland diggings, where the grains are comparatively coarse. It has become well-known in the placers of the American river, and in Plumas, Shasta, Trinity and Siskiyou counties, California. The Bee Gum district in Shasta county, the Hay Fork district in Trinity county, and the deposits along the Trinity from Chapman's mine, south of Junction City, northward to beyond North Fork, are most promising.

Conditions of Occurrence

Though platinum-metals are so frequently found in many of the gold-placers of the region including Trinity, Shasta and Siskiyou counties, their occurrence in this region is by no means universal. There seems, for example, to be no platinum in the Weaverville placers on the Trinity. The platinum-bearing placers confirm the accepted idea that the platinum originates in the serpentine rock in which this region abounds, for the platinum-bearing gravels are sure to be closely associated with some prominent serpentine ridge. Nevertheless, no platinum has yet been found in place within the area named.

A hurried trip through this region enabled the writer to learn, by the analytical aid of Dr. Waldron Shapleigh, that in the Bee Gum district of Shasta county, at Hay Fork, and at Chapman's mine on the Trinity, osmiridium makes up perhaps the greater part of the mixture of platinum-metals. At Chapman's mine, Colonel Barrows obtained 30 ounces of small nuggets, averaging one-third inch in diameter, apparently altogether

too hard for platinum, and yet considerably coarser than is usual for osmiridium, which has the habit of occurring in very small scales. Dr. Shapleigh has shown that these nuggets yield a small amount of platinum on treatment with aqua regia, and then fall apart into the ordinary scales of osmiridium. He has found, also, that the Pacific beach platinum often contains more than 90 per cent. of osmiridium. This explains the fact that little effort has been made to mine the platinum; for, until recently, the osmiridium has had practically no value.

At the time of my visit, platinum was noticed also in the placers near Grant's Pass, Oregon, and by examining numerous samples of black sands, traces of platinum were found in the Snake river from Bakersville to Lewiston, and in a sand reported to come from Miles City, Montana.*

In examining the well-known platinum-localities on Granite creek, near its junction with Tulameen Fork, in British Columbia, it was estimated that the placers contained about one-fifth as much platinum as gold. I could get no test for osmium, but Dr. Hoffmann, of the Canadian Geological Survey, has found samples of platinum yielding as high as 25 per cent., and on the average about 10 per cent., of osmiridium.

In further search for the platinum-metals, the writer collected heavy sands from placer-mines in California, Oregon, Washington, Idaho, Montana and Alaska. These samples averaged 4 pounds in weight. The sand was first separated by ordinary assay-sieves into about nine sizes coarser than 20-mesh; through 20-, 40-, 60-, 80-, 100-, 120-, 160-, and then 200-mesh. Each size was then in good condition for easy separation of the highly magnetic portion by a rude form of separator. By limiting the magnetic separation to the highly magnetic particles, very little of gold or platinum was removed with the magnetic portions—as the panning of these portions proved.

By panning each size, and then counting (or weighing, where the amount was considerable) the flakes of gold and platinum, a fair idea of the proportion of platinum to gold could be gained. As the sieving was carried to such uniform sizes, it was possible, by counting weighed amounts, to estimate the unit-

* Dr F W Traphagen confirms this find of platinum at Miles City, Montana. The concentrated sand examined by him contained 10 per cent. of platinum

TABLE I.

Pan-Tests of Platinum-Bearing Gold-Sands.

Post-Office and State	Weight of Sample Ounces	Value of Platinum Metals Per Ton	Percentage of Platinum to Gold
<i>California</i>			
Crescent City, Del Norte county	80	\$ 04	17
Smith River, Del Norte county	23	54	6.8
Crescent City, Del Norte county (South Fork, Smith river)	62	681 31	2.230
Trinity Center, Trinity county	35	28	79
Burnt Ranch, Trinity county	45	13 09	104
Weaverville, Trinity county	20	0	0
Big Bar, Trinity county	40	3 75	11
Junction City, Trinity county	49	1984 18	
Hawkins Bar, Trinity county	63	4 05	34
Randsburg, Kern county	50	0	0
Wilson Creek, Humboldt county	45	02	8
Big Lagoon, Humboldt county	60	0	0
China Flat, Humboldt county	25	177 08	138
Orleans, Humboldt county	36½	6 87	50
Hamburg, Siskiyou county	20	0	0
Hamburg, Siskiyou county	55	86	280
Sawyers Bar, Siskiyou county	79	2 39	31
Oak Bar, Siskiyou county	123	54	12
Fort Jones, Siskiyou county	51	07	1
Sawyers Bar, Siskiyou county	45	07	3
Klamath River, Siskiyou county	63	2 40	51
Rock Ranch, Siskiyou county	29	51	26
Callahan, Siskiyou county	58	7 02	134
Hornbrook, Siskiyou county	19	18	06
Callahan, Siskiyou county	25	0	0
Scott River, Siskiyou county	9	1 83	.6
Happy Camp, Siskiyou county	48	50.97	148
Cecilville, Siskiyou county	20	2 01	14
Cecilville, Siskiyou county	14½	.15	8
Walker, Siskiyou county	37	0	0
Shasta River, Siskiyou county	30	0	0
Klamath River, Siskiyou county	30	0	0
Gottville, Siskiyou county	20	0	0
Camptonville, Yuba county	37	.32	4
Camptonville, Yuba county	50	0	0
Quincy, Plumas county	40	0	0
Laporte, Plumas county	50	0	0
Butte Valley, Plumas county	35	0	0
Butte Valley, Plumas county	30	0	0
Slate Creek, Sierra county	40	0	0
Gibsonville, Sierra county	50	0	0
Gibsonville, Sierra county	20	0	0
Chico, Butte county	40	5 46	8 4
Magalia, Butte county	60	30	1.2
Inskip, Butte county	20	0	0
Brownsville, Butte county	30	0	0
Michigan Bluff, Placer county	56	.34	1
Michigan Bluff, Placer county	59	19	.1
Grizzly Flats, Eldorado county	40	0	0
Smith Flat, Eldorado county	40	0	0
Railroad Flat, Calaveras county	50	0	0
Mokelumne Hill, Calaveras county	84	02	2
Genesee, Plumas county	63½	06	.008

TABLE I.—*Continued.*

Post-Office and State	Weight of Sample Ounces	Value of Platinum Metals Per Ton	Percentage of Platinum to Gold
<i>Oregon</i>			
Denmark, Curry county	25	\$1 08	300
Denmark, Curry county.			
No 1	49½	06	20
No 2	44½	0	0
No 3	50½	15	18
No 4	48½	24	10
No 5	47½	25	60
No 6	45	32	121
No 7	50	0	20
No 8	57½	21	50
No 9	53	03	3 6
No 10	50	0	0
No 11	52	01	12
2 miles north of Pistol river, on Oregon Beach	118	06	8
2 miles south of Pistol river, on Oregon Beach	60	0	0
<i>Idaho</i>			
Rocky Bar, Elmore county	50	0	0
Princeton, Latah county	60	0	0
<i>Montana</i>			
Forest, Missoula county	50	0	0
<i>Alaska</i>			
Sand from beach north of Lituya bay	100	0	0

weights of flakes of the different sizes, and thus to approximate roughly the total weight of gold and platinum obtained.

The results are shown in Table I.

In addition to the sands mentioned above, about 25 ounces of Klondike gold-dust was examined, and only a grain or two, probably of platinum, was found.

A number of concentrates collected by Mr. A. H. Brooks, of the U. S. Geological Survey, from the Tanana river district in Alaska, and also the beach-sands brought from Cape Nome by Mr. Brooks and Mr. Schrader, showed no platinum.

The total results above reported show that, if all the sands examined were considered together, there would be about half as much of the platinum-metals as of gold.

With regard to the percentage of platinum in the sands from various parts of the Pacific coast, Dr. Shapleigh has furnished the following table.

TABLE II

		Highest Per cent	Lowest Per cent
Bee Gum district, Shasta Co., Cal	{ Platinum	20	13 5
	{ The other platinum-metals .	84	79
Hay Fork district, Trinity Co., Cal.	{ Platinum	73	30
	{ The other platinum-metals .	58	18.
Trinity River district, Cal	{ Platinum	27	15
	{ The other platinum metals .	80	72
Crescent City, Del Norte Co., Cal	{ Platinum	11	8.
	{ The other platinum-metals .	83	46
Port Orford, Ore	{ Platinum	47.	15
	{ The other platinum-metals .	83	23

The "other platinum-metals" include iridium, osmium, ruthenium, rhodium and palladium

The Telluride-Ores of Cripple Creek and Kalgoorlie.

BY T A RICKARD, STATE GEOLOGIST, DENVER, COLO

(Canadian Meeting, August, 1900)

THE lodes of Cripple Creek, Colo., partake of the composition of the geological formation which they traverse. The prevailing rocks are andesitic breccia, lying upon granite, and also bodies of phonolite, trachytic phonolite, nepheline-basalt, etc., penetrating both the granite and the breccia. At Kalgoorlie, in West Australia, the prevailing rock is schistose, and has not been certainly identified, though microscopic sections indicate the probability that it was originally an acid eruptive. The lodes are essentially bands, more highly schistose than the encasing rock, and impregnated to a notable degree with disseminated pyrites and secondary calcite.

During 1899 Cripple Creek produced 425,590 tons of ore, having a gross value of \$15,658,254; during the same period the output of Kalgoorlie was 467,048 tons, valued at \$17,724,587.

In chemical composition, the ores at Cripple Creek and Kalgoorlie, respectively, present differences equally interesting to the petrographer and the metallurgist. In both cases we have to deal with altered eruptives as the matrix of the ore, but the much older rock of Kalgoorlie has undergone more decompo-

sition than that of Cripple Creek To the metallurgist the difference is of greater importance, especially in the milling of the low-grade ores.

The Kalgoorlie schistose lodes carry only a small amount (2 to 12 per cent) of alumina, the replacement of the feldspar having advanced very far, while, on the other hand, the impregnation of secondary carbonates of lime and magnesia, aggregating from 5 to 15 per cent., gives the ore a strong dolomitic ingredient. The silica contents average between 45 and 60 per cent. Titaniferous iron accounts for the presence of from 1 to 2.5 per cent. of titanac acid.

The Cripple Creek ore has a composition which approximates that of the prevailing rocks, and therefore the alumina is very high—from 15 per cent in the granitic ores to 25 per cent. in those occurring with phonolite and its allied dike-rocks Of lime and magnesia there is only from a trace of the latter to 4 per cent of the former. The silica ranges from 55 to 70 per cent., being highest in the granitic ores.

In sulphur and iron the two districts present no very marked difference, although there is more pyrite disseminated through the ore at Kalgoorlie than at Cripple Creek, the average percentage of sulphur being from 4 to 8 at Kalgoorlie and from 1.5 to 2 at Cripple Creek. The iron is a little higher in both, but in about the same ratio.

From a smelter's standpoint the Kalgoorlie ore is the better, being less siliceous, and (what is more important) carrying a much smaller percentage of alumina. It is the practice in Colorado to limit the amount of alumina in the charge of the lead-smelting furnaces to about 5 per cent. The Cripple Creek ores, which carry about four times this proportion, are smelted only in limited quantities mixed with other ores, so as not to impair the fusibility of the slag.

The absence of copper and lead in the ores of both districts does not affect the reduction by smelting; but it obviates difficulties which might otherwise arise in the wet treatment at the mills.

The dolomite in the Kalgoorlie lodes renders chlorination unsuitable as a method of treatment, on account of the fact that the lime and magnesia, resulting from the roasting of the carbonates, absorb the chlorine before it can unite the

gold, and thus prevent any solvent action upon the precious metal until the former have been satisfied. On the other hand, the presence of the carbonates tends to neutralize the acidity due to the sulphatization of pyrites and renders the ore very amenable to cyanidation, the process now employed at Kalgoorlie. The schistose character of the lode-stuff causes it to slime easily in wet-crushing; and the mechanical difficulties arising from this fact have prompted the general adoption of dry-crushing, in order to expedite subsequent leaching and filtration.

The Cripple Creek ores are docile to cyanidation and chlorination alike. The latter requires, of course, a dead roast; and for this reason the cyanide-process, which does not necessarily require the roasting of oxidized and partially oxidized ores, had an advantage in the early days of the district. Now, however, it is recognized that, apart from chemical reasons, it is economical to subject the oxidized ores to roasting, on account of the resulting betterment in the leaching and filtering of the pulp.

The adaptation to conditions which characterizes all successful industrial progress is to be seen in both of the mining centers under discussion. Cripple Creek was born amid conditions of advanced industrial facilities; Kalgoorlie was found in a desert, more than 300 miles from any commercial center. Each, in its successful development, has served as a telling illustration of the energy and skill of the English-speaking race.

Telluride-ores have become an important source of gold during the past five years on account of the discoveries made in Colorado and West Australia. They have been treated as something quite new and phenomenal. As the result of the success of the two districts there grew up a notion that this mode of gold-occurrence indicates ore-bodies of specially persistent nature—a fallacy akin to the older one which assumes an enrichment with depth as a general characteristic of gold-veins. Tellurides have been mined in Transylvania for a century, and they have been known in Colorado, as important ores of gold and silver, since 1872—two districts, the La Plata mountains and Boulder county, yielding them in commercial quantities. In none of these regions have they been characterized by special continuity in depth. On the contrary, until

Cripple Creek, and then Kalgoorlie, commenced to make a record, it was generally held, among those who were aware of the facts, that telluride ores were erratic in behavior and difficult to treat. The former proposition is not more true of them now than of gold-deposits in general; while the latter has been largely modified by the advance of metallurgical practice.

As is well known, the tellurides, or combinations of tellurium with the metals, are similar to the combinations formed with sulphur and selenium. The first determination of this interesting group of minerals is due to Klaproth, who, in 1802, recognized them in the ores of Zalathna, in Transylvania. Tellurium is a non-metallic element. In its chemical combinations it acts in a manner analogous to sulphur, which it appears at times to replace. Native tellurium is a tin-white, brittle substance with a bright metallic luster. Its commercial value is \$3.50 per ounce, but the demand for it in the arts is very slight, and a few shipments demoralize the market, as is the case with most of the rare earths. It is extremely uncommon both at Cripple Creek and at Kalgoorlie, but in Boulder county, Colo., it is frequently encountered. A mass weighing 25 pounds was found in 1877 at the John Jay mine, near Jimtown. In Gunnison county, in Southern Colorado, it has lately been found at the Vulcan mine, in mica schist, associated with a lode of gold-bearing pyrite, which, in the oxidized zone, includes masses of native sulphur.

Kalgoorlie affords the finest specimens of the telluride of gold, calaverite, in generous splashes of lustrous yellow, which glorifies the dull-looking schistose rock. Analyses* yield nearly 42 per cent. of gold, with less than 1 per cent. of silver. The specific gravity is given as 9.377. At Cripple Creek, good specimens of calaverite are rare; but it occurs finely disseminated through the ores, although somewhat ob-

* Two may be quoted, the first by J C H Mingay, analyst to the Geological Survey of New South Wales, and the second by E S Simpson, analyst to the Geological Survey of West Australia.

	No 1	No 2
	Per cent	Per cent
Gold,	41 76	41 56
Tellurium,	56 64	57 79
Silver,	80	65

seured by the presence of sylvanite. Analyses* indicate the average composition as ranging from 38 to 40 per cent. in gold, with about 3 per cent. of silver. The specific gravity is given as 9. The Cripple Creek variety therefore makes a very close approach to Gent's original determination† of the specimens from the Stanislaus mine, in Calaveras county, Cal., the locality from which the mineral derived its name.

In Boulder county, Colo., which yielded some of the earliest specimens, a splendid mass of calaverite was found in 1877 at the Melvina mine by Henry Neirkirk, a Dutchman, who, while prospecting, drove his pick into a mass of soft, clay-like, unctuous material, and, on withdrawing it, found that it was gilded. The mass consisted‡ of lemon-colored oxide of tellurium containing fine particles of amorphous gold, the two substances being the product of alteration from the bronze calaverite which Neirkirk found deeper down, associated with magnesite and fluorite. This dioxide of tellurium, or tellurium-ocher, has been found in Transylvania. It is very rare because of its marked affinity for ferric salts, with which it forms a definite compound, the tellurite of iron.

The tellurite of iron, which Knight§ was the first to determine, has a light-brown color and a bright yellow streak. It occurs also in a specimen which I obtained|| at Kalgoorlie. As

* Two analyses are given herewith, the first by W. F. Hillebrand, chemist to the U. S. Geological Survey, and the other by F. C. Knight, chemist to the Boston and Colorado Smelting Co.

	No 1 Per cent	No 2 Per cent
Gold,	38.95	40.14
Tellurium,	57.27	56.22
Silver,	3.21	3.63

† Which, according to Dana, was

	No 1 Per cent	No 2 Per cent
Gold,	40.70	40.92
Tellurium,	55.89	56.00
Silver,	3.52	3.08
Specific gravity,	9.043	

‡ According to my informant, Mr. Richard Pearce.

§ "A Suspected New Mineral from Cripple Creek," a paper read before the Colorado Scientific Society, October 1, 1894, by F. C. Knight. His analysis gave a percentage of Fe_2O_3 , 32.72; TeO_2 , 65.45, and H_2O , 1.83. The luster is dull, the fracture brittle and uneven, and the hardness between 3 and 4.

|| Through the courtesy of Mr. J. W. Sutherland, of the Lake View Consols mine.

a mineral it has only an academic interest; but the chemical reactions of which it is the result play an important part in the treatment of telluride ores. Namely, in roasting these ores, the tellurium is not driven off with the sulphur, but, as soon as it has volatilized, it becomes oxidized to TeO_2 , and is fixed in the roasted charge by combining with the oxide of iron due to the calcination of the pyrites in the ore. What tellurium does escape, and is subsequently found in the flue-dust, is carried away mechanically by the draft. This is the experience of our reduction-works. Mr. Richard Pearce has made laboratory-tests* to elucidate the matter, and has found that as much as 96.4 per cent. of the tellurium has remained in the ore after it had been roasted.

In nature a kindred action probably occurs, the decomposition of the gold-bearing telluride in the presence of oxidizing pyrite liberating the gold with the formation of the tellurite of iron. The gold, thus set free in a metallic condition, has characteristics which readily distinguish the surface-ores of all telluride lodes. At Mt. Morgan, it was found, in 1886, that the dull-looking gold would not amalgamate in the stamp-mill. Dr. Leibius, of the mint at Sydney, decided, as the result of experiments, that the gold, which was of remarkable purity, was probably coated with an oxide of iron. In 1893, I remarked the similarity between the gold of the famous mine in Queensland and the specimens given to me at the Pike's Peak and Garfield Grouse mines, on Bull hill, Cripple Creek, but it was not until 1897† that the resemblance was traced to a common cause, the derivation of the gold from tellurides. The soft, brown gold resulting from the alteration of tellurides has the appearance of gold precipitated from solution. Its pasty, spongy, but slightly compact character has caused it to be named "mustard gold" at Kalgoorlie. It occurs in splashes like yellowish clay, and can be detected by scratching, which burnishes it, so as to exhibit the unmistakable glint of the precious metal. At Cripple Creek, very perfect pseudomorphs after sylvanite and krennerite are obtainable. In the Gold King vein, patches of these can be seen in a series of quartz geodes,

* "Occurrence of Tellurium in Oxidized Form Associated with Gold," by Dr Richard Pearce *Proc Colo Sci Soc*, vol v, pp 144-147.

† When Mr E S Simpson, at Perth, West Australia, showed me a specimen of petzite which he had found in the sulphide-ores of the Mt Morgan mine

the gold looking, as the miners express it, "like splinters of rotten wood." Free gold at Cripple Creek has invariably that appearance which characterizes the metal when it has originated from the disintegration of tellurides; but at Kalgoorlie, ordinary gold, in a bright and crystalline condition, also occurs. It is usually in coarse particles, the size of which hinders complete extraction by leaching and becomes a factor in the ore-treatment. At most of the cyanide-mills there are supplementary amalgamating-tables, over which the tailings are conducted, after they have been discharged from the vats, so as to extract any of these larger particles which may have escaped solution. They would escape, not only by reason of their larger dimensions, but because they would lack that spongy character, conducive to quick leaching, possessed by gold which has resulted either from the alteration of tellurides in nature or from their decomposition in the roasting-furnace.

Sylvanite, although it does not carry the largest portion of the gold obtained from the Cripple Creek ores, is the telluride most frequently seen in the specimens from that district. It is uncommon at Kalgoorlie, but is particularly characteristic of the ores of Boulder* county, especially in the mines around Salina. The name of this beautiful mineral originates from the historic mining region, Transylvania, where the compounds of tellurium were first detected. Its brilliant silver-white twinned crystals are often distributed over the faces of pieces of rock so as to look like Arabic writing. Hence the alternative name of "graphic tellurium." One of the first analyses of a Cripple Creek specimen was made in 1894, by Mr. Richard Pearce, who found that the composition agreed closely with that obtained by Genth, in 1874, from the sylvanite of the Red Cloud mine, in Boulder.† August Frenzel gives the analysis‡ of a specimen

* There is a township of Boulder, adjoining Kalgoorlie, and actually nearer to the big mines of that district than the latter. It must not be confounded with the district, of the same name, in Colorado, which is referred to above.

† The analyses referred to are

	Pearce Per cent	Genth Per cent
Tellurium,	60 61	59 78
Gold,	25 45	26 36
Silver,	13 94	13 86

See "Further Notes on Cripple Creek Ores" *Proc Colo Ser Soc*, vol v, p 15

‡ *Tsch Min Mitth*, 1897, xvii., 288, 289. The analysis is Tellurium, 58 63, gold, 36.60, silver, 3 82 per cent.

from Kalgoorlie which he labels sylvanite; but the composition is much nearer that of krennerite, the prismatic, brilliant, vertically-striated crystals of which occur in the ores of the Moon-Anchor and other mines on Gold Hill, Cripple Creek. The color of krennerite is like that of sylvanite, but it has a greater tendency to a slight brassy-yellow tinge. It is the most beautiful of all the tellurides

While visiting the Kalgoorlie mine, at Kalgoorlie, in 1897, I received a specimen of so-called "black tellurium," which was said to be the native metal itself. Under a simple test in a tube over the blowpipe it volatilized completely, but left a deposit of quicksilver globules at the cold end of the tube. It was coloradoite,* the telluride of mercury, which was first detected by the industrious Genth in specimens from the Mountain Lion mine at Magnolia, Colorado. It is iron-black, with a sub-conchoidal fracture and the rich unctuous luster which characterizes several other tellurides, notably calaverite. At Kalgoorlie, native mercury and native amalgam have also been found. In addition to these previously-known minerals, there is a variety of coloradoite which has been named, by Mr E. F. Pittman, kalgoorlite.† As the crystallographic features do not differ materially from coloradoite, it can hardly be considered as more than an impure variety of the latter, and may be looked upon as a mixture of petzite and coloradoite.‡

At the Associated Mines, Kalgoorlie, there occurred a min-

The composition of coloradoite is, according to Dana: Tellurium, 38.5; mercury, 61.5 per cent. An impure variety is named lionite, after the Mountain Lion mine.

† "Kalgoorlite, a New Telluride Mineral from Western Australia," by E. F. Pittman, Government Geologist. *Record of the Geol. Surv. of N. S. Wales*, vol. v, part iv, pp. 203, 204.

‡ *Op cit.* J. C. H. Mingay, Analyst to the N. S. W. Geological Survey, gives the analysis of Mr Pittman's specimen. I add those of the other two minerals.

	Kalgoorlite Per cent	Coloradoite Per cent	Petzite Per cent
Mercury,	10.86	61.5	.
Gold, . .	20.72	.	25.5
Silver, . .	30.98	.	42.0
Copper,	.05	.	..
Sulphur, .	.13	..	.
Tellurium, .	37.26	38.5	32.5

eral which resembled this supposed kalgoorlite. The analyses* of Mr. W. F. Grace proved that it was petzite.

Petzite is not common, either at Kalgoorlie or at Cripple Creek. In the former district it occurs both in the Associated mine, as stated, and also in the Great Boulder Main Reef; and therefore, presumably, in other mines. At Cripple Creek I have seen it in specimens from the Geneva, on Gold Hill, and in the ore of the Porter Gold King, above Anaconda. Petzite is the characteristic mineral of the Golden Fleece mine, an isolated occurrence of tellurides, in Lake county, Colo., which, between 1894 and 1896, produced \$1,400,000 from a comparatively small tonnage of ore. It is very probable that future investigations will lead to the recognition of several new varieties of tellurides in both of the two districts under discussion; but it will be necessary for this purpose to obtain crystalline specimens, so that analyses of composition may be supplemented by the measurement of crystal-angles.

Of the minerals which seem to be specially associated with tellurides two are particularly notable fluorite and roscoelite. Fluorspar, or fluorite, the fluoride of calcium, is a frequent companion of lead-ores, not so much in the United States as in England and Saxony. In Colorado it characterizes the telluride-ores of both Boulder county and Cripple Creek, especially the latter.† Hence it was at one time supposed to be a favorable indication of richness in the lode; but later experience has exploded this generalization, together with several others. The prevailing color of the fluorite at Cripple Creek is from amethyst to purple. Large crystals are rare. Much of the coloring which serves as a beautiful background for the lustrous tellurides is but a stain upon the silicified breccia and other

* The specimens came from the 200-ft level of the Tetley shaft. The specific gravity is given, in a letter from Mr. Grace, as 9, and the hardness as 2.5 to 3. The two analyses were as follows

	No 1	No 2
	Per cent	Per cent
Silver,	40 47	40 55
Gold,	24 64	24 62
Tellurium,	34 60	34 83
Mercury,	29	.00

The traces of mercury were probably due to a slight admixture of coloradoite.

† Fluorite also accompanies the native tellurium at the Vulcan mine in Gunnison county. *Vide supra*, p. 711

lode-matter. The presence of fluorite in the granite outside the gold-mining area checks the inferences which might otherwise be made from the fact of its prevalence in the veins.

Fluorite does not characterize the lodes at Kalgoorlie, but calcite may be said to be a feature of their mineralization, particularly in view of the fact that the ordinary free-gold veins of the neighboring districts, such as Coolgardie, do not carry it in notable amount. Calcite is rare at Cripple Creek. It is occasionally encountered, lining cavities in the eruptives. The small percentage of lime in the ores, as reported by the smelters, comes from the fluorite. Calcite is frequent in the telluride lodes of Boulder.

Roscoelite has a peculiar interest for the student of telluride-ores. It is a brownish-green micaceous mineral, belonging to the hydro-mica group, and remarkable as carrying a large percentage of vanadium *. This uncommon mineral was found in handfuls,† in the form of small dark greenish-brown micaceous spangles, by the miners who worked the placer-ground in the ravine below Sutter's mill, California, where gold was first discovered‡ in California. It accompanies the tellurides of Boulder to such an extent that the miners have got into the way of considering it a gold-bearing mineral in itself, instead

* Two analyses, the first by Genth and the second by Roscoe, are given by Dana. The following are the principal constituents, small amounts of FeO, MnO and Na₂O being omitted in this quotation.

	SiO ₂	V ₂ O ₅	Al ₂ O ₃	MgO	K ₂ O	H ₂ O
	Per cent	Per cent	Per cent	Per cent	Per cent.	Per cent
No 1,	47.69	20.56	14.10	2.00	7.59	4.96
No 2,	41.25	28.85	14.34	1.96	8.25	3.06

Hillebrand has lately analyzed a sample from the Stockslager mine on Granite Creek in El Dorado county, Cal., the locality from which Genth and Roscoe also obtained their samples. From five partial analyses, determining different constituents, he calculated the following probable average composition.

SiO ₂	V ₂ O ₅	Al ₂ O ₃	K ₂ O	H ₂ O
Per cent	Per cent	Per cent	Per cent	Per cent
45.17	24.01	11.54	10.37	4.69

See "On Roscoelite," by W. F. Hillebrand and H. W. Turner, *Am. Jour. of Sci.*, Fourth Series, vol. VII, p. 451, June, 1899.

† As I was informed by one of those who worked in the locality mentioned and gave me a small vial filled with the material referred to. See also description by W. H. Turner in the article cited above.

‡ On January 19, 1848.

of a mere accessory. The Boulder variety is grayish-green to olive-green. It frequently stains the quartz and other vein-stuff, so as to give them a strong green color, resembling that of ordinary chlorite. In 1897 several specimens of the ore from the Great Boulder Main Reef mine at Kalgoorlie were sent to me, and I thought that roscoelite was discernible. Mr. Pearce subsequently made* an investigation which confirmed this opinion.

Roscoelite has not yet been recognized at Cripple Creek, but chlorite occurs freely, especially in the Elkton and Mary McKinney lodes. Various forms of chlorite are also in part responsible for the prevailing green coloration of the protogine of Boulder and the schistose bands of Kalgoorlie. Analytical tests might succeed in separating a particular variety as a characteristic of these ores. It is, to say the least, very suggestive that the telluride-veins in the granite of Cripple Creek, the schist of Kalgoorlie and the protogine of Boulder, should all be characterized by the presence of chlorite. Of course, it may be regarded simply as the product of the decomposition of the biotite and augite in the prevailing country. Nevertheless, it remains an interesting coincidence.

The small amount of quartz occurring in these telluride-veins is a feature worthy of notice. Quartz is so common a matrix for the precious metal that it has been called by some the "mother of gold." At Kalgoorlie a notable amount of quartz is considered an indication of poverty, at Cripple Creek there is more quartz; but it never predominates to the extent which marks the ordinary gold-veins of California and Victoria. Much of the secondary quartz, as distinguished from the siliceous ground-mass of the country itself, is hydrous and opalescent. This encrusts the cracks and cavities resulting from the most recent lines of disturbance. In Boulder county, the quartz takes the form of a dark flinty substance, the "hornstone" often referred to in descriptions of the lodes.

* "Notes on a Peculiar Occurrence of Tellurium in a Gold-Ore from the Great Boulder Main Reef, Western Australia," by Richard Pearce. *Bulletin Colo. Sci. Soc.*, No 8, 1897. Mr Pearce gives an analysis by F. C. Knight, showing SiO_2 , 43.65; V_2O_5 , 27.11; Al_2O_3 , 9.95; CaO , 1.43; MgO , 1.51 per cent.

The Influence of Silicon and Sulphur on the Condition of Carbon in Cast-Iron.

BY HENRY M HOWE, PROFESSOR OF METALLURGY, COLUMBIA UNIVERSITY,
NEW YORK CITY *

(Canadian Meeting, August, 1900)

I. THE INFLUENCE OF SILICON ON THE CONDITION OF CARBON IN CAST-IRON.

It has been generally accepted that the presence of silicon in cast-iron leads to the formation of graphite; and this has been explained by saying that the silicon lowers the solvent power of iron for carbon at and somewhat below the freezing-point, so that, in the presence of silicon, the iron is unable to retain in solution or combination the whole of the carbon with which it has united while molten, and therefore expels the excess of carbon in the form of graphite, during and immediately after solidification

Probably the best way to study this question would be to examine pure cast-irons, *i.e.*, those containing nothing but iron, carbon and silicon, which at the same time should have been saturated with carbon when molten. But the data for such a study are not at hand; so we must turn to commercial pig-irons as they are made in the blast-furnace, and before their composition has been changed by remelting.

Much evidence has been offered of late, tending to oppose the theory of the action of silicon above set forth. Some of this evidence will be examined here.

1 *Mr Bachman's Results.*

In particular, Mr. F. E. Bachman† has published a collection of analyses of cast-iron, in which the proportion of graphite at first appears to be nearly independent of the proportion of silicon present. Thus, in his Table LI., we find that with pro-

* SECRETARY'S NOTE —The manuscript of this paper was received May 18, 1900

† *Trans*, xxviii, 769

gressively increasing silicon-content the graphite-content varies in the most confusing way. I condense his results in the following table

TABLE I.—*Mr. Bachman's Results with Pig-Iron.*

	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silicon average	0 75	1 25	1 83	2 13	2 36	2 62	2 87	3 14
Silicon limits	0 50 to 1 00	1 00 to 1 50	1 50 to 2 00	2 00 to 2 25	2 25 to 2 50	2 50 to 2 75	2 75 to 3 00	3 00 to 3 25
Total carbon .	3 818	3 724	3 412	3 580	3 69	3 691	3 652	3 775
Graphite .	3 867	3 865	3 170	3 383	3 499	3 515	3 481	3 574
Combined carbon	0 451	0 359	0 242	0 197	0 19	0 176	0 171	0 201
Sulphur . ..	0 03	0 023	0 024	0 025	0 027	0 030	0 028	0 023
Number of cases	5	9	12	15	29	30	22	16

But looking at the matter more closely, I find the influence of silicon well marked. It must be remembered that, by our silicon-theory, silicon influences the graphite-content not directly, but indirectly, by lessening the solvent power of iron for carbon, thus lessening the proportion of combined carbon, and thus, in turn, indirectly increasing the proportion of graphite, provided the total carbon-content remain constant. But this provision does not necessarily hold good the total carbon may vary much, and, since the graphite-content is simply the complement of the combined carbon, *i.e.*, the excess of the total carbon over the saturation-point for combined carbon, any variation in the total carbon will cause corresponding variations in the graphite-content. This is exactly what we find in Mr. Bachman's results, namely, that as the silicon increases from an average of 0.75 to one of 1.83 per cent., the combined carbon diminishes progressively from 0.451 to 0.242 per cent, as demanded by our silicon-theory. The graphite-content does not, however, increase correspondingly, for the very simple reason that the total carbon-content diminishes rapidly.

Lest it be thought that to decrease the combined carbon from 0.451 to 0.242 per cent. is a very trifling result to follow so great a change in silicon-content, let us remember that our cast-irons with 0.451 and 0.242 per cent. of combined carbon may be held to correspond, on one hand, to steel of 0.451 per cent. of combined carbon (with graphite intermixed as a foreign

body), and, on the other hand, to steel of 0.242 per cent. of combined carbon, with like admixture of graphite. In other words, the difference in combined carbon is that which exists between some spring-steel and some strong structural steel, sufficing to cause the enormous difference which exists between their properties, even in the annealed state. This aspect of the case is discussed by the writer in a separate paper on "The Constitution of Cast-Iron," presented at this meeting.

As the silicon rises still further, from an average of 1.83 to an average of 2.87 per cent., the combined-carbon-content further diminishes, still in accordance with our silicon-theory; but the diminution is extremely slight.

Turning, now, to Table II (Mr. Bachman's Table LII.), we find much the same condition of things. As the silicon rises from 1.00 to 2.86 per cent., the combined carbon progressively diminishes from 0.563 to 0.346 per cent. That the absolute amount of combined carbon is much higher for given silicon-content than in his Table LI, is readily understood in view of the greater sulphur-content in his Table LII. As in Table LI, the graphite-content does not follow any simple law, for the excellent reason that, as before, the total-carbon-content varies greatly.

TABLE II—*Mr. Bachman's Results with Remelted Cast-Iron.*

	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silicon average	1.00	1.38	1.62	1.90	2.12	2.37	2.61	2.86	3.08	3.32	3.63	4.10
Silicon limits {	0.70	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	4.00
	to	to	to	to	to	to	to	to	to	to	to	to
Total carbon	3.314	3.322	3.4627	3.423	3.3483	3.3900	3.24	3.256	3.4456	3.235	3.144	3.100
Graphite.	2.751	2.773	2.969	2.935	2.9125	2.94	2.85	2.91	3.097	2.802	2.857	2.635
Combined carbon	0.563	0.549	0.5036	0.488	0.4856	0.45	0.39	0.35	0.35	0.43	0.29	0.465
Sulphur	0.11	0.10	0.08	0.07	0.07	0.07	0.09	0.07	0.07	0.11	0.07	0.10
No of cases	6	14	11	12	12	12	11	9	7	4	3	2

The teaching of Mr. Bachman's results is (1) that, as the silicon rises from 0.75 to about 2 per cent., there is a marked decrease in combined carbon; and (2) that this decrease becomes less and less marked with further and further rise in silicon. I call attention particularly to this point, the far greater influence of the first increment of silicon than of later increments.

Unfortunately the number of results presented by Mr. Bachman which bear upon the second of the above inferences is very small—a defect which I have tried to remedy by the new evidence which I now present.

2 *The Author's Results*

In order to throw further light on the influence of silicon on carbon-condition, I have plotted in Figs. 1 and 2 the combined carbon, graphite and total carbon of about seven hundred pig-irons, with carbon as ordinate and silicon as abscissa.* In order to lessen the masking influence of sulphur, Fig. 1 includes only those cast-irons which contain less than 0.04 per cent. of sulphur, and Fig. 2 those only which contain from 0.04 to 0.08 per cent. Besides these I plotted two similar diagrams, one with sulphur from 0.08 to 0.13, and the other with sulphur from 0.13 to 0.20 per cent. But the number of cases at hand within these limits was so small that these diagrams are not worth publishing.

To lessen the influence of variations in manganese and phosphorus, no cast-irons containing more than 1.50 per cent. of manganese or 0.55 of phosphorus are here given.

Fig. 1 confirms the inference as regards combined carbon, which I have drawn from Mr. Bachman's results. For while for given silicon-content the combined carbon, indeed, varies greatly, yet on the whole there is a very decided and marked decrease in combined carbon as the silicon rises from zero to 1 per cent., and a further, though less marked, decrease as the silicon rises still further to 2 per cent. With further increase

* In the construction of the diagrams, Figs 1 and 2, the percentages of combined and of graphitic carbon in each specimen analyzed are laid off (marked by a cross or a circle, respectively) upon an ordinate drawn through the point which indicates its percentage of silicon, and the percentage of total carbon (being the sum of these) is laid off as a dot upon the same ordinate. In reducing the diagrams for engraving, the subordinate cross-lines showing the precise percentages have been omitted, so that it may be difficult to trace in the engraving the record of each analysis. But the purpose of this graphic summary is simply to show the general law; and this is sufficiently indicated by the engraved diagrams. Thus, Fig 1 shows that in the pig-irons containing from 0 to 0.04 per cent. of sulphur, an increase of silicon from 0 to 2 per cent., while it is accompanied by no marked change in total carbon (which remains at or a little below 4 per cent.), yet is accompanied by a marked decrease in combined carbon, very rapid at first and slower afterwards.

of silicon there appears to be a slight further decrease of combined carbon.

Thus, among the great number of cases with more than 2 per cent. of silicon shown in Fig. 1, there are but five in which the combined carbon exceeds 1 per cent., and in only one of these does it reach 1.50 per cent.; in the large number of cases with between 1 and 2 per cent. of silicon, the combined carbon exceeds 1 per cent. in only nine cases, while two-thirds of all the cases with less than 1 per cent. of silicon have more than 1 per cent. of combined carbon, and one-third of them have more than 3 per cent. of combined carbon. And every iron which has less than 0.50 per cent. of silicon has more than 2 per cent. of combined carbon.

Turning now to the graphite, the complement of the combined carbon, we find this same condition of things reflected. Most of the cases have over 3 per cent. of graphite; the only cases which have less than 2 per cent. of graphite have also less than 1.20 per cent. of silicon, and of the cases with less than 1 per cent. of silicon, more than one-fifth actually have less than 1 per cent. of graphite. But, while the influence of silicon stands out clearly in Fig. 1, we cannot trace it in Fig. 2, perhaps because the number of cases here is so small.

Note to Figs. 1 and 2.—The cases here plotted are believed to be normal pig-irons, or cast-irons strictly comparable with pig-irons. As has already been said, none are here given which contain more than 1.50 per cent. of manganese, or more than 0.55 per cent. of phosphorus, or more than 0.08 per cent. of sulphur; and none are given in which it was known or suspected that by sudden cooling, by casting in thin sections, or otherwise, the proportion of combined carbon was materially affected. For these reasons many otherwise valuable data had to be omitted; for instance, those of Mr. G. R. Johnson, in "The Action of Metalloids on Cast-Iron," *Journ. Iron and Steel Inst.*, 1898, ii, p. 200, and Kerpely's, Percy's and Ledebur's data.

The cases given are taken from the following sources:

1. The records of the Warwick Iron Co., kindly supplied by President E. S. Cook.

2 "The Melting-Point of Cast-Iron," by Dr. Richard Moltenke, a paper read before the Pittsburgh Foundrymen's Association, Oct. 24, 1898, Table I.

Fig. 1

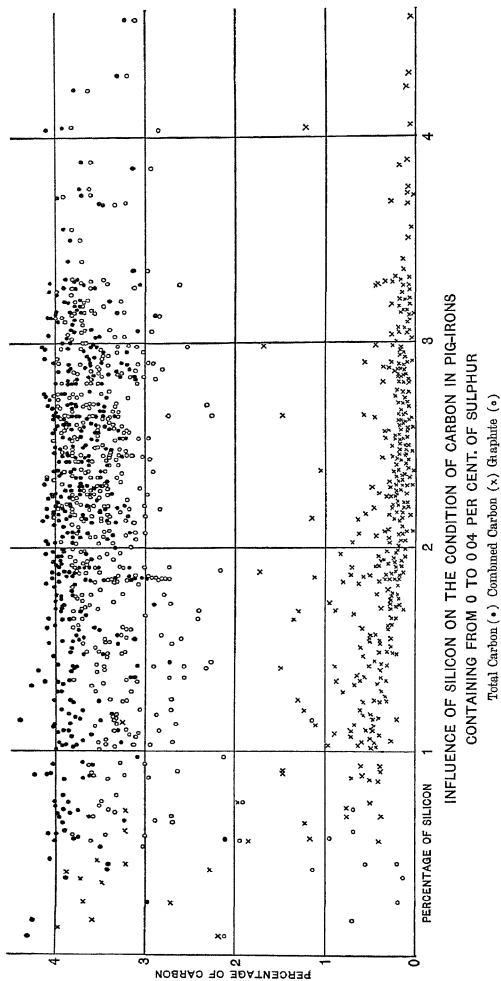
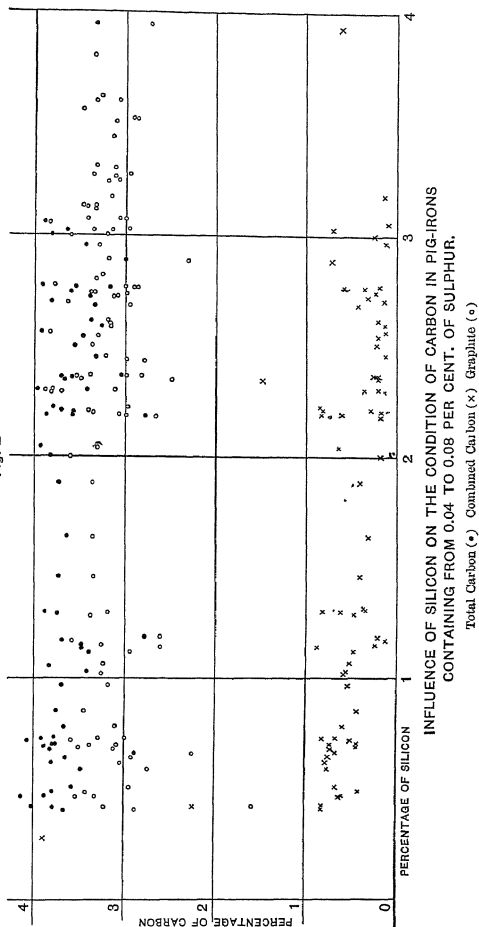


Fig. 2



3 "The Silicon-Control of Cast-Iron," by F. E. Bachman, *Trans.*, xxviii, p. 769, Oct, 1898

4. The records of a large Welsh steel-works.

5 "Transverse Strength of Cast-Iron," by W. J. Keep, *Trans. Am. Soc. Mech. Eng.*, xvi., p 1082

6. Watts, *Dictionary of Chemistry* (Edition of 1875), iii., pp. 332-3.

7. Kerl, *Grundriss der Eisenhüttenkunde*, 1875, pp 27 and 44

8. Cast-Iron in Railway Practice, G. R. Henderson and W. W. Davis, *American Engineer and Railroad Journal*, Jan. 19, 1899, p 4.

9. The author's private notes, and various minor publications.

We need hardly be surprised at the width of the band occupied in Fig. 1 by the combined-carbon crosses. Silicon-content is only one of the things which influence the quantity of combined carbon; and the influence of other impurities, of the casting temperature, and of the rate of cooling, may suffice to account for the width of this band.

3 *Desilicidizing Processes.*

We have a further very important piece of evidence tending to prove that the first increment of silicon, say from zero to 0.75 per cent, causes a decrease in the combined-carbon-content, in the fact that whenever, in any process of converting cast-iron into wrought-iron or steel, we remove the silicon, we thereby immediately turn a gray cast-iron into a white one, even though the total percentage of carbon present remains nearly constant. This is true of puddling, of the Bessemer process, of the refinery process, and of the Bell-Krupp or pig-washing process. In each of these the silicon is quickly removed at the beginning of the operation, and a sample then taken shows that an initially gray cast-iron has, by the simple removal of silicon, been turned from gray into white, often with only very slight change in the total carbon-content.

4. *Turner's Results.*

By melting together in various proportions two cast-irons which were about half-saturated with carbon, one of them rich in silicon, the other nearly free from it, but otherwise of like composition, Prof. Turner* obtained a series of cast-irons in

* *Jour. Iron and Steel Inst.*, 1886, 1, p 174

which silicon was practically the only variable. I condense his results in Table III

TABLE III — *Turner's Results.*

	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silicon	0.19	0.45	0.96	1.37	1.96	2.51	2.96	3.92	4.74	7.33	9.80
Total carbon	1.98	2.00	2.09	2.21	2.18	1.87	2.23	2.61	2.63	1.86	1.81
Graphite	0.38	0.10	0.24	0.50	1.62	1.19	1.13	1.81	1.66	1.48	1.12
Combined carbon	1.60	1.90	1.85	1.71	0.56	0.68	0.80	0.20	0.37	0.38	0.69

On first inspection these results seem to teach that an increase of silicon from 0.19 to 0.96 per cent. causes an increase of combined carbon from 1.60 to 1.85 per cent. But Fig. 1 shows us that, for a given percentage of silicon, the percentage of combined carbon varies very greatly, when the percentage of silicon is below 1 per cent. Prof. Turner's decrease of combined carbon we refer, after examining Fig. 1, to causes other than increase of silicon. And his results, as a whole, bear out those in Fig. 1 by showing, both (1) that the combined carbon on the whole decreases as the silicon increases, and (2) that this decrease is not smooth and regular, but is greatly influenced by other variables, thus agreeing with the considerable width of the combined-carbon band in Fig. 1.

They agree moreover with the general principle that it is not the graphite-content, but the combined-carbon-content that is affected directly by the silicon-content; and that the graphite is simply the difference between the total carbon (on one hand) which happens to be present, and the combined carbon (on the other hand), which represents the saturation-point of the iron for carbon, as determined by the silicon-content and other causes. For though Prof. Turner's cast-irons contain only about 2 per cent. of total carbon, or about half as much as those in Fig. 1, yet for given silicon-content they have about the same amount of combined carbon as those of Fig. 1, nearly the whole of the carbon-deficit of his irons, relatively to mine, being represented by their graphite-deficit.

The reason why I have not included his results in Figs. 1 and 2 is that they do not represent normal and nearly saturated pig-iron as it issues from the blast-furnace, because they have only about half the normal carbon-content of such iron.

Among the great number of cast-irons given in Fig. 1, only five contain less than 3 per cent. of total carbon, and the great majority have from 3.50, or even from 3.75, to 4.20 per cent.

5. Keep's and Moldenke's Results.

The results of Mr W. J. Keep, which I have rearranged in Tables IV. and V., and graphically in Fig. 3, bring out the same law. Here, again, as the silicon increases, the combined carbon decreases progressively, though irregularly—rapidly at first, then more slowly.

TABLE IV.—*Influence of Silicon-Content on Carbon-Condition, as Indicated by W. J. Keep's Results.*

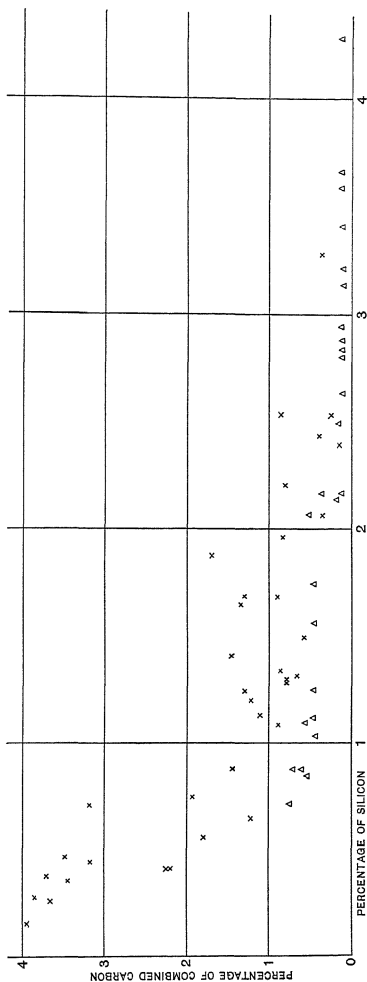
(Rearranged from *Trans Am Soc Mech Eng*, xvi., pp 1099 *et seq*.)

A FOUR-INCH SQUARE BARS															
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silicon	0.88	0.88	1.03	1.12	1.57	2.07	2.50	2.81	2.84	2.95	3.15	3.22	3.42	3.50	4.67
Total carb	3.53	3.91	3.84	4.01	3.27	3.75	3.63	3.28	3.31	3.30	3.16	3.31	3.19	3.33	3.52
Graphite	3.13	3.31	3.42	3.55	2.82	3.25	3.55	3.20	3.23	3.22	3.08	3.23	3.11	3.72	3.42
Combined carbon	0.70	0.60	0.42	0.46	0.45	0.50	0.13	0.08	0.08	0.09	0.07	0.08	0.08	0.11	0.10
Sulphur.	0.041	0.039	0.009	0.030	0.022	0.044	0.030	0.090	0.027	0.025	0.090	0.028	0.059	0.007	0.030
B THREE-INCH SQUARE BARS															
Silicon	0.72	0.85	1.10	1.25	1.75	2.15	2.17	2.17	2.64	2.89	2.94	3.20	3.67	3.75	4.30
Total carb	3.81	4.00	3.86	3.88	3.24	3.82	3.70	3.71	3.36	3.37	3.28	3.11	3.48	3.15	3.30
Graphite	3.05	3.48	3.32	3.37	2.80	3.67	3.36	3.60	3.28	3.28	3.14	3.04	3.38	3.03	3.19
Combined carbon	0.76	0.52	0.54	0.46	0.44	0.15	0.34	0.11	0.08	0.09	0.06	0.07	0.10	0.11	0.11
Sulphur	0.049	0.030	0.089	0.010	0.020	0.010	0.036	0.044	0.022	0.029	0.094	0.091	0.030	0.087	0.028
C TWO-INCH SQUARE BARS															
Silicon	0.82	0.90	1.00	1.22	1.33	1.50	1.80	2.00	2.49	2.62	2.91	3.36			
Combined carbon	0.80	0.53	0.46	0.49	0.56	0.37	0.36	0.37	0.09	0.15	0.09	0.11			
D. ONE-INCH SQUARE BARS															
Silicon	0.79	0.93	1.14	1.29	1.40	1.69	1.73	2.55	2.65	2.69	2.75	3.75			
Combined carbon	1.25	0.88	0.54	0.44	0.42	0.48	0.45	0.36	0.16	0.38	0.12	0.09			
E HALF-INCH SQUARE BARS															
Silicon	0.83	0.91	0.98	1.09	1.16	1.73	2.13	2.42	2.56	2.74	2.77	2.84			
Combined carbon	1.46	1.24	0.53	0.70	0.67	0.48	0.45	0.35	0.32	0.37	0.27	0.29			

In Mr. Keep's five series we find the following marked contrasts between the great decrease of combined carbon as the silicon rises from about 0.80 to about 2.50 per cent., and the slight further decrease of combined carbon as the silicon rises

*

Fig 3



INFLUENCE OF SILICON ON THE CONDITION OF CARBON IN CAST-IRON,
ACCORDING TO THE OBSERVATIONS OF Mr. W.J.KEEP AND Dr. R.MOLDENKE.

Mr. Keep's results (x), Dr. Moldenke's results (Δ)

still more. The algebraic-average decrease of combined carbon is 0.74 per cent. in the former case, against only 0.06 in the latter.

TABLE V.—*Showing that an Increase of Silicon from 0.80 to about 2.50 Per cent Diminishes the Combined Carbon Much More than Does a Further Increase of Silicon.*

(Compiled from Mr Keep's Data)

Size of Bars, Inches	As Silicon Rises from about 0.80 to about 2.50 Per cent, Com- bined Carbon Decreases			As Silicon Rises Beyond about 2.50 Per cent, the Combined Carbon Decreases			
	From	To	Difference	From	To	Difference	UpperSil- con Limit
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
4x4 . . .	0.65	0.13	-0.52	0.13	0.10	-0.03	4.67
3x3 . . .	0.52	0.08	-0.44	0.08	0.11	+0.03	4.30
2x2 . . .	0.80	0.09	-0.71	0.09	0.11	+0.02	3.36
1x1 . . .	1.25	0.36	-0.89	0.36	0.09	-0.27	3.75
$\frac{1}{2}$ x $\frac{1}{2}$. .	1.46	0.32	-1.14	0.32	0.29	-0.03	2.84
Algebraic average difference			-0.74			-0.06	

As Mr Keep's results represent foundry cast-irons, we naturally find among them no data as to the influence of variations of silicon below 0.75 per cent.

In Tables IV and V. we can trace the influence of the rate of rapid cooling in restraining the separation of graphite, and thus increasing the combined-carbon content. The smaller the cross-section, the faster does the metal cool; and as we pass from the 4 by 4 in. to the $\frac{1}{2}$ by $\frac{1}{2}$ in. bars, the combined carbon-content for a given silicon-content increases greatly; though of course, because of the other variables, sulphur, manganese, etc., this increase is not regular.

Dr. Moldenke's results, shown in Table VI, afford simply another instance of the greater influence of the early than of the later increments of silicon. Among his cases we may say roughly that—

As the Silicon Increases			The Combined Carbon Decreases		
From Per cent	To Per cent	Difference Per cent	From Per cent	To Per cent	Difference Per cent
0.14	1.30	1.16	4.00	0.80	3.20
1.30	3.00	1.70	0.80	0.30	0.50

Fig. 3 represents Dr. Moldenke's results graphically, on the same plan as that of Figs. 1 and 2, except that the percentage of combined carbon only is given.

TABLE VI—*Moldenke's Results* *

	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silicon	0 14	0 25	0 28	0 36	0 38	0 42	0 42	0 42	0 45	0 47	0 56	0 65
Graphite					0 14	1 14	1 55	0 42	0 20	0 54	1 95	2 63
Combined carbon	3 98	3 70	3 90	3 48	3 74	2 38	2 23		3 21	2 52	1 84	1 24
Sulphur	0 037	0 033	0 044	0 040	0 032	0 026	0 045		0 037	0 076	0 022	0 020
Manganese	0 10	0 09	0 11	0 09	0 16	0 13	0 16		0 18	0 20	0 34	0 26

TABLE VI—*Continued*

	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silicon	0 71	0 75	0 89	1 09	1 13	1 20	1 25	1 20	1 50	1 22	1 34	1 41
Graphite	0 68	1 90	2 63	3 07	2 66	2 70	2 70	3 16	3 22	3 60	3 10	2 30
Combined carbon	3 22	1 95	1 47	0 90	1 12	1 23	1 31	0 80	0 80	0 67	0 87	1 48
Sulphur	0 038	0 028	0 037	0 014	0 027	0 022	0 022	0 020	0 042	0 020	0 030	0 033
Manganese	0 09	0 63	0 48	0 33	0 24	0 37	0 76	0 50	0 59	0 20	0 42	1 39

TABLE VI—*Concluded*

	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Silicon	1 50	1 65	1 69	1 88	1 97	2 07	2 21	2 40	2 44	2 54	2 54	3 29
Graphite	3 15	2 41	2 40	2 17	3 26	3 44	2 89	3 43	3 43	2 26	3 48	3 70
Combined carbon	0 59	1 36	1 31	1 72	0 83	0 35	0 80	0 13	0 38	1 49	0 24	0 35
Sulphur	0 032	0 038	0 039	0 028	0 018	0 039	0 041	0 032	0 048	0 038	0 020	0 038
Manganese	0 61	0 32	0 46	0 54	0 59	0 28	0 25	0 90	0 57	0 50	0 39	0 82

6. *Summary*—These results, taken as a whole, point towards the following law *In normal and relatively pure commercial pig-irons, (1) as the silicon increases the combined carbon progressively decreases; (2) this decrease is rapid at first, especially as the silicon rises from zero to 0.75 per cent, and then slower and slower, (3) this influence of silicon is often masked by that of other variables*

So far as I know, the second part of this law is here enunciated for the first time.

That the combined carbon decreases on the whole as the silicon increases, seems to be beyond reasonable doubt, that the first additions of silicon cause a greater effect than the later ones, seems almost equally certain. Both these features of this law are supported by the results of Bachman, Keep, Moldenke and the author; Turner's support in a general way the first part of the law. His first four results oppose the second part of the law; but the number of cases here represented is so small that we cannot attach much weight to them.

* From his paper on "The Melting-Point of Cast-Iron," read before the Pittsburgh Foundrymen's Association, Oct. 24, 1898

It is indeed possible that the data in Fig. 1 may somewhat exaggerate the influence of the very first additions of silicon, because the number of cases with less than 1 per cent. of silicon is much smaller than we could wish; indeed, Dr Moldenke's form a very large proportion of them.

II. THE INFLUENCE OF SULPHUR ON THE CONDITION OF CARBON IN CAST-IRON

The influence of sulphur in raising the saturation-point of solidifying iron for carbon, and thus increasing the combined carbon-content and lowering the graphite-content of cast-iron, can be traced by comparing Figs. 1 and 2, and we can even make a first rough approximation to its quantitative effect in this respect, at least for cast-irons containing from 1 to 2 per cent., and for those containing from 2 to 3 per cent. of silicon. The following table gives the average combined carbon for the cast-irons which I studied in preparing Figs 1 and 2

TABLE VII.—*The Influence of Sulphur on the Proportion of Combined Carbon in Pig-Iron*

PER CENT OF SULPHUR	1 TO 2 PER CENT OF SILICON		2 TO 3 PER CENT OF SILICON	
	Average Combined Carbon	Approximate No of Cases	Average Combined Carbon	Approximate No of Cases
0 to 0.04	0.35	300	0.175	175
0.04 to 0.08	0.42	17	0.304	32
0.08 to 0.13	0.864	10	0.14	1
0.13 to 0.20	0.93	3		0

NOTE.—The averages in the first line were estimated by the eye; the rest were calculated

The following preliminary estimate of the quantitative effect of sulphur may be worth recording for comparison with the results of later investigators.

TABLE VIII.—*A First Approximate Estimate of the Influence of Sulphur on the Proportion of Combined Carbon in Pig-Iron.*

	Per cent	Per cent
Silicon	1 to 2	2 to 3
Sulphur.	0 to 0.08	0 to 0.08
Increase of combined carbon for each 0.01 per cent increase of sulphur	0.02	0.03

These numbers are only the roughest approximations. But even first approximations to the truth are acceptable when no others are at hand; and when the data do not justify final conclusions, opinions and estimates are better than nothing, provided we bear in mind their provisional and tentative character.

POSTSCRIPT

Since the foregoing was written, the publication of Mr. S. R. Church's book, "Analyses of Pig-Iron,"* has supplied additional data, which, together with all the data found in Volumes I. to VIII., inclusive, of the Journal of the U. S. Association of Charcoal Iron Workers, I have now plotted on the plan used in preparing Fig. 1, taking the same limits of composition as regards manganese, phosphorus and sulphur. The general results are closely like those of Fig 1, and the data therefore support, in a general way, the conclusions which are drawn in the present paper. The following table shows how, in this new lot of analyses, the combined carbon decreases as the silicon increases. The diagram itself is not here given, since this table gives the results clearly enough.

TABLE IX.—*Relation Between Silicon-Content and Combined Carbon-Content in Pig-Iron. Additional Data.*

Silicon, per cent	0 00 to 0 75	0 75 to 1 50	1 50 and upwards
COMBINED CARBON	Number of Cases		
Per Cent			
Over 1 10	4	0	0
From 0 75 to 1 10	13	2	0
" 0 50 to 0 75	6	13	6
" 0 25 to 0 50	1	8	27
" 0 00 to 0 25	1	4	31
Total	25	27	64

Here we note that the combined carbon exceeds 0.75 per cent. in 68 per cent. of the irons which have less than 0.75 per cent. of silicon, but in only 2 per cent. of the irons which have more than that quantity of silicon.

* Seymour R. Church, San Francisco, 1900

The Micro-Structure and Physical Properties of Cast-Iron, as Affected by Heat-Treatment, Especially in the Manufacture of Malleable Cast-Iron.

BY A T CHILD AND W P HEINEKEN, NEW YORK CITY

(Canadian Meeting, August, 1900)

THIS paper presents the results of a series of experiments made in the metallurgical laboratory of Columbia University, New York City. The object of the investigation was to determine, as far as possible, the changes in micro-structure and physical properties caused by short periods of heat-treatment and the longer malleable cast-iron process. It was proposed to do this by means of micro-photographs, heating- and cooling-curves, and tensile tests after the various heat-treatments.

I. MICRO-CONSTITUENTS OF IRON AND STEEL

The list of the micro-constituents of iron and steel has grown till now it includes seven different substances, called ferrite, cementite, pearlite,* martensite, austenite, sorbite and troosite. Only the first five of these are mentioned in this paper, to facilitate the understanding of which, the following brief definitions are given.

1. Ferrite (named by Prof. Howe) is, chemically, iron free from carbon. It is the softest of the constituents, and is not colored by etching, except when long-continued. Under the microscope it is easily determined by its regular polygonal structure; or, if structureless, as in malleable cast-iron, by the ease with which it is scratched. Ferrite appears in mild steel in small amount, in grey cast-iron, and in malleable cast-iron.

2. Cementite (also named by Prof. Howe) is now generally conceded to have the formula Fe_3C . It is the hardest of the micro-constituents, having the hardness indicated by 7 of the mineralogical scale; and hence it is always left in relief after

* Originally spelled pearlyte The present form has been adopted by Prof Howe

polishing on a soft or yielding material, such as chamois skin stretched over a wooden block. It is not colored even by long-continued etching. Under the microscope it appears very white and glistening. It is always structureless, and occurs in irregular patches or bands. It is found in high-carbon steel and in white and mottled pig-iron.

3. Pearlite (also named by Prof. Howe) is a compound made up of alternate laminae of ferrite and cementite. This lamination gives it the prominent pearly luster which suggested its name. Very slight etching colors pearlite, and is usually sufficient to bring out the structure very well. Little difficulty is found in determining pearlite under the microscope, the parallel laminae giving it a characteristic structure. It is found in iron and steel cooled very slowly from high temperatures. In steel of 0.80 C. it composes the entire mass.

4. Martensite (named by Mr. Osmond in honor of Prof. Martens) is the non-magnetic hardening-component of steel. It has a very pronounced needle-like structure, and is differentiated from pearlite by the fact that the needles cross each other in directions parallel to the three sides of a triangle, while the laminae of pearlite, though not always straight, never cross each other. Considerable practice in etching is required to develop this constituent satisfactorily, as a slight over-etching will spoil the structure completely. Iodine colors it brownish. A weak solution of NH_4NO_3 , as used by Mr. Osmond, is excellent to bring out martensite. Martensite is found in steel and iron quenched above the recalescence-point and in tempered steel. It forms the entire structure of 0.80 C.-steel quenched.

5. Austenite (first recognized by Mr. Osmond and named by him in honor of the distinguished English metallurgist, Roberts-Austen) is not frequently found. It has a peculiar structure, sometimes similar to martensite; but the needles are shorter and broader than those of martensite. It occurs also in zig-zag lines, crossing each other quite irregularly; and sometimes the structure resembles oat-chaff, scattered rather promiscuously over the surface of the section. This constituent has been found by Mr. Osmond in steel carrying more than 1 per cent. of carbon, and also by us, we think, in white pig-iron. To develop it, the material must be quenched very rapidly from very high temperatures.

II. THE MALLEABLE CAST-IRON PROCESS.

This process has been practiced for many years both in Europe, where Réaumur published its fundamental principles in 1722*, and in this country, where it was first carried on with success by Seth Boyden at Newark, N. J. It still holds a position of considerable prominence in our iron industry. Commercially, malleable cast-iron occupies a place between grey cast-iron and wrought-iron. It has about the tensile strength of the former and somewhat less elongation than the latter. It is very useful for castings which are to have exact proportions and at the same time possess a considerable degree of malleability. Articles not over an inch in diameter can be pretty completely decarburized, and thus rendered malleable throughout. Larger pieces, as, for instance, coupling-irons, can be greatly increased in toughness by decarburization from the outside for some distance inward. The pig chosen for castings to be thus treated is usually white or mottled, and low in phosphorus, silicon and sulphur.

The conduct of the process is briefly as follows: Castings, made from white or mottled pig-iron, as stated above, having been packed tightly, surrounded by mill-scale or red hematite, in cast-iron annealing-boxes, the covers of which are luted on, are heated for about 10 days at an average temperature of 950° C. In packing, care is taken that the castings do not touch each other at any point, otherwise the annealing will not proceed properly. Some form of direct-firing furnace is used in the annealing. During the last day the furnaces are gradually cooled down. The annealed castings must be well cleaned in a tumbling-apparatus before they are fit for market.

The process is chemically a decarburization, due to the strongly oxidizing conditions which prevail throughout this treatment. The main part of the carbon contained in white cast-iron exists there as the carbide, Fe_3C . This breaks down easily, under the annealing conditions, to what Ledebur calls "temper-carbon," which is slowly oxidized to CO by the influence of the packing, and is burned to CO_2 at the box-openings. The carbon remaining in the castings at the end of the process

* *L'art de convertir le fer forgé en acier, et l'art d'adoucir le fer fondu*, Paris, 1722
See Ledebur's *Handbuch der Eisenhüttenkunde*, p. 933, under *Glühfrischen*.

is nearly all graphitic. This is due of course to the fact that graphitic carbon is very slowly oxidized. The silicon of the original pig must be low, since high silicon nearly always implies high graphitic carbon, the presence of which would lengthen the process, and give a weak, very porous product at the end, as is well shown by our experiments. Both phosphorus and sulphur in appreciable quantities are extremely deleterious to the product.

The "malleable cast-iron" thus obtained has a tensile strength of about 45,000 pounds to the square inch and from 3 to 7 per cent. of elongation, while the original pig possessed no elongation and was brittle as glass.

III STATEMENT OF EXPERIMENTS.

A number of white and grey cast-iron bars, 0.5 in. thick and 18 in. long, were obtained by pouring all the white from one ladle, and all the grey from another, so as to secure uniformity in each class. The grey cast-iron contained C, 3.55; Si, 3.08; and the white cast-iron, C, 2.25; Si, 0.75 per cent.

Through the kindness of Messrs Isaac Johnson & Co., we were allowed to make four heats in their annealing-furnaces. For these experiments three white and three grey bars respectively were tightly packed with red oxide of iron into 3-in. iron pipes, fitted with caps at either end. Great care was taken that the bars should not touch each other at any point. Four heats were made, 10, 20, 30 and 40 days in length, respectively, at an average temperature of 950° C. We cannot be very positive as to the temperature, which was measured only from Seger cones, placed in the pipes. In this way we estimated the maximum temperature to be about 1000° C. Sections of white and grey cast-iron were made after each heat, polished, etched, and examined under the microscope. Micro-photographs were also taken from each section.

The bars from these heats were pulled in a Riehle testing-machine. In these tests, the elastic limit was determined by the drop of the beam, and is therefore only approximate.

In addition to these experiments, pieces of white and grey cast-iron were heated to 1100°, 1200°, and 1300° C., and some were cooled slowly, while others were quenched in iced brine. Similar pieces were held at the same temperature for 3 hours,

and then treated as above. Sections were made, and micro-photographs of the sections were taken from all these pieces.

Again, similar pieces were packed in hematite and held at 1000° C. for 6 hours, in order to determine how far annealing would proceed in that time. The pieces to be cooled slowly in these experiments were packed in lime to insure a uniform rate of cooling. The temperatures were recorded with a Le Chatelier thermo-electric pyrometer. The heats were made in a small gas-furnace.

In preparing the metallic sections, we used for polishing a small machine, driven by a motor, to which the polishing-wheels were easily attached. The series usually employed was. (1) a pretty fine emery-wheel, (2) a wooden wheel, covered with pretty fine emery-paper, (3) a leather-covered wooden wheel, upon which wet flour of emery was rubbed as needed. The finishing was done first with wet rouge, and finally with a jeweler's buff-wheel, well filled with dry rouge. In etching, the tincture of iodine was used with excellent results. For developing martensite and austenite, the dilute ammonium nitrate solution suggested by Mr. Osmond (2 parts of the crystallized salt to 100 parts of water) gave the best results. Good results were often obtained by etching rather deeply and then polishing down on chamois skin stretched over a block of soft wood. In photographing, Beck's vertical illuminator was used, and a Welsbach burner furnished the light. The Cramer plates, which gave the best negatives, were exposed, on an average, 10 minutes. Our best prints were made with "carbon velox."

IV. THE EFFECT OF HEAT-TREATMENT, AS SHOWN BY MICRO-PHOTOGRAPHS OF THE MATERIAL AFTER TREATMENT.

Figs. 1, 2 and 3 are photographs of the original white cast-iron. Fig. 3 shows the structure of a section cut longitudinally from the bar. The white constituent in relief is cementite, the hardening-constituent of white cast-iron. The large white patches well illustrate its usual occurrence in white cast-iron. The remainder of the section is a peculiar granular form of pearlite, not commonly encountered. Fig. 3 shows how cementite tends to arrange itself in lateral strata normal to the surface of the bar.

Figs. 4 and 5 are photographs of white cast-iron heated in

red oxide of iron for 10 days. Fig 4 shows the structure near the edge of the bar; and Fig 5, the structure at the center. One notices at once the entire change of structure, especially the absence of cementite, as compared with Figs. 1, 2 and 3. The section, Fig 4, is composed almost entirely of structureless ferrite. It is very porous, by reason of the oxidation and removal of the finely-divided "temper-carbon" This seems to have been very widely disseminated through the mass of the iron after the breaking-down of the carbide. Its finely-divided state seems to have made it fall a far more easy prey to oxidation than the graphitic carbon. The structure at the center contains a little pearlite in patches, and is not so porous. The higher carbon-content at the center explains the decreased number of the holes. An analysis of the outer half of the section showed 0.35 C, and one of the center showed 1.5 C.

Fig. 6, from the center of the section, shows the white pig, after 20 days' annealing, to be a porous mass of ferrite and pearlite; the latter rather poorly defined, and the former coming to be in excess, due to the longer heating. Examination of the section showed on its edge a thin film of pearlite, possibly accounted for by the re-absorption of small amounts of carbon to form cementite, which changed to pearlite during the slow cooling. This point, however, requires further investigation. The major portion, however, was porous, structureless ferrite, with a few patches of pearlite near the center.

Fig. 7, taken near the center of the section, shows the structure of cast-iron heated 30 days. The structure does not differ much from Fig. 6. A little fine pearlite is seen in scattered patches through the ferrite. The entire remainder of the section was composed of structureless ferrite.

Fig 8 is from a photograph of white iron heated 40 days. Most of the structure is ferrite, with still a little pearlite in patches. Practically the whole bar has become structureless ferrite. The very porous character of the iron becomes at once the main cause of its weakness.

From these photographs it will be seen that the process is practically complete inside of ten days. In fact, after a 6-hour heat, made by us, we were able to cut the bar entirely through with a hack-saw, showing that the carbide is nearly broken down within that time. But this was undoubtedly due mainly

to the heat rather than to oxidation. The pieces used in this 6-hour experiment were packed similarly to those of the 10-, 20-, 30- and 40-day heats.

Subsequent heats show only a slow removal, by the same process of oxidation as in the first heat, of the small quantity of carbon still remaining. It is seen that the temper-carbon yields quite easily to oxidation, leaving as traces the fine pores so frequently remarked in the photographs. The strength of the iron will be considered under another heading.

Fig. 9 shows the structure of a piece of white iron, heated to 1150°C. , and cooled slowly. The obvious great change in grain shows the effect of the slow cooling from a temperature considerably above the recalescence-point, which has developed the large grains of pearlite to an unusual degree. The network of the grain is cementite, which is found also in patches here and there in the pearlite grains themselves. The rapidity with which white iron is decarburized is attested by the fact that a thin ring of ferrite was noticed around the outside of this section.

Fig. 10 shows the structure of a piece of white iron held at 1100°C. for three hours, and cooled slowly. The effect of the longer heating is seen in the irregular net-work of cementite about the grains of pearlite. The section showed a band of ferrite about the outside, the main part of the structure being irregular grains of pearlite, as shown by the photograph.

Fig. 11 presents a remarkable structure. The photograph was taken from the center of a section of white iron heated to 1000°C. and quenched in iced brine. It would seem that the structure is composed mostly of Osmond's austenite.

Fig. 12 shows the structure of most of the outer portion of the section. The constituent of the grain appears to be austenite, and the net-work is martensite. The presence of so much austenite seems to be somewhat contradictory to the experience of Mr. Osmond, who says that austenite is found only in steel of not less than 1 per cent. carbon, from which point to 1.60 per cent. it increases, and above 1.60 begins to diminish. A glance at the photograph will show that, at least in the case of white iron, quenched rapidly from high temperatures, this constituent appears to form the main part of the structure. It seems to act here as the eutectic, martensite being the constituent separating out in excess.

Fig. 13 shows the structure of a piece of white iron held at 1200°C for three hours. Faint outlines of extremely large grains are seen, even larger than the grains in Fig. 9. The structure of the grain is pearlite, and the plain net-work cementite. The photograph well shows the effect upon the grain of slow cooling from high temperature.

Figs. 14, 15 and 16 also present a remarkable structure. They are taken from a section of white iron, heated to 1300°C and quenched in iced brine. Here also, as in Figs. 11 and 12, the major part appears to be austenite. An examination of the whole section showed a series of concentric rings, having different structures, namely a thin band of austenite outside, next, a band of the structure indicated in Fig. 16, viz. large, round grains of austenite, with a coarse net-work of martensite; third, a rather narrow band of unusually regular hexagonal grains, as shown in Fig. 14. Unfortunately, the photograph is not as clear as could be wished, but a careful scrutiny of the figure will show large hexagonal grains, two short sides being parallel. The fine net-work is martensite, and the grain is austenite. Finally, there is a small central portion of structureless austenite. Fig. 15 shows the appearance before etching of the section shown after etching by Fig. 16. It may be remarked, however, that the iron was in a pasty state, bordering on fusion, when quenched; and it seems to us that this fact, and the sudden cooling from very high temperature, may partly explain the structure. The presence of austenite at both the center and the outside of the section may be due to partial decarburization (austenite replacing pearlite), since some time was occupied in raising the iron to the required temperature.

Fig. 17 shows the structure of a piece heated to 800°C . and cooled slowly. The structure is practically the same as in the original white iron, and the section shows that the grain does not break up till after that temperature has been passed.

Fig. 18 shows the structure of the original grey pig-iron near the center of the section. It is made up of graphite and ferrite. The outer portion is nearly all ferrite with some graphite.

Fig. 19 shows the center of a section from grey cast-iron, heated 10 days. The structure is unchanged.

Fig. 20 exhibits the structure near the edge of this section, showing how some of the graphite has been replaced by pearlite in the course of slow annealing and cooling. The main part of the outer band consists of patches of pearlite and a pretty large proportion of ferrite. An analysis of the outer part of the section showed 0.70 per cent C., the center being unchanged.

Fig. 21 is a photograph taken from near the edge of a section of grey iron, heated 20 days. The structure is ferrite, much more porous than the white iron, by reason, partly, of the more porous character of the grey iron, and partly of the oxidation and removal of graphite. The structure of the section is distinctly banded. About the unchanged dark core at the center comes a thin band of pearlite grains, then a band of structureless ferrite, and lastly a thin band of pearlite around the outside of the section. The marked increase of pearlite is the cause of the increased strength shown in the table of tests.

Fig. 22 shows the structure of a section from the 30-day heat. The photograph was taken from the band of pearlite surrounding the dark core. Except that the dark core was smaller, the structure was the same as in Fig. 21.

Figs. 23 and 24 are from the 40-day heat. The section was composed almost entirely of structureless ferrite, a very little pearlite was observed at its center and edge. Fig. 23 was taken from near the center of this section, and shows both the structureless ferrite and the unchanged dark core. Fig. 24 was taken from near the edge. It will be seen from these figures that the oxidation of the graphite is a very slow process. The extremely porous and rotten condition in which the removal of the graphite leaves the iron, deprives it of much practical usefulness. In the pulling-tests, it was observed that the iron had no elongation, and broke with a dull report. The tests from the 20- and 30-day heats, however, point strongly to pearlite as an element of strength.

Fig. 25 shows a section of grey iron which had received the same treatment as the white iron of Fig. 9, being heated to 1150° C. and cooled slowly. It is composed entirely of large, irregular grains of pearlite with a net-work of ferrite.

Fig. 26 was taken from near the center of a section which

Fig. 1.



Fig. 2.



Cross-Sections of the Original White Iron. (300 Diameters.)

Fig. 3.



Longitudinal Section of the Original White Iron. (300 Diameters.)

Fig. 4.



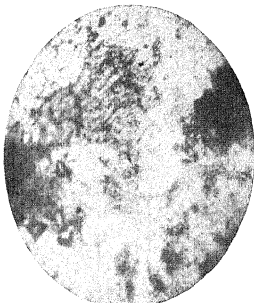
White Iron Treated 10 Days at 950°. Edge of Bar. (300 Diameters.)

FIG. 5.



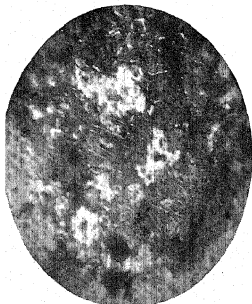
Same as Fig. 4. Center of Bar.
(300 Diameters.)

FIG. 6.



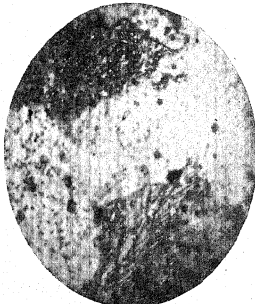
White Iron Treated 20 Days at
950°. (300 Diameters.)

FIG. 7.



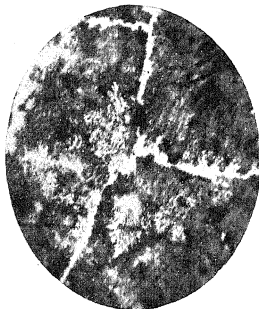
White, Treated 30 Days at 950°. (300 Diameters.)

FIG. 8.



White, Treated 40 Days at 950°. (300 Diameters.)

FIG. 9.



White, Heated to 1150° and Cooled Slowly. (300 Diameters.)

FIG. 10.

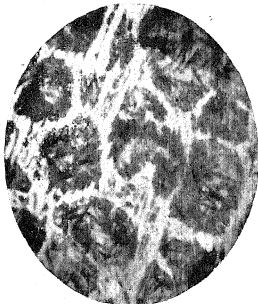


White, Kept at 1100° for 3 Hours and Cooled Slowly. (300 Diameters.)

FIG. 11.



FIG. 12.



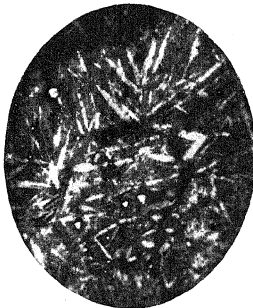
White Iron, Heated to 1000° and Quenched at 0° . Fig. 11 from the Center Section, and Fig. 12 from the Edge of the Section. (300 Diameters.)

FIG. 13.



White Iron, Held 3 Hours at 1200° and Cooled Slowly. (300 Diameters.)

FIG. 14.



White, Heated to 1300° and Quenched at 0°. (300 Diameters.)

FIG. 15.

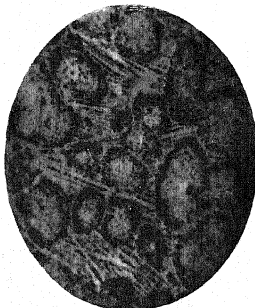


FIG. 16.



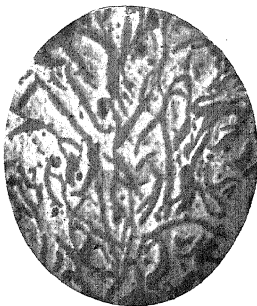
White Iron, Heated to 1300° and Quenched at 0°. Fig. 15 taken before, and Fig. 16 after, etching. (300 Diameters.)

FIG. 17.



White, Heated to 800° and Cooled Slowly. (300 Diameters.)

FIG. 18.



Original Grey Cast-Iron. (300 Diameters.)

FIG. 19.



FIG. 20.



Grey Iron, Treated 10 Days at 950°. Fig. 19, from Center; Fig. 20, from near Edge of Section. (300 Diameters.)

FIG. 21.



Grey Iron, Treated 20 Days at
950°. (300 Diameters.)

FIG. 22.



Grey Iron, Treated 30 Days at
950°. (300 Diameters.)

FIG. 23.

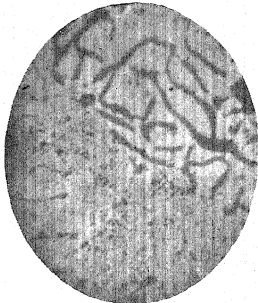
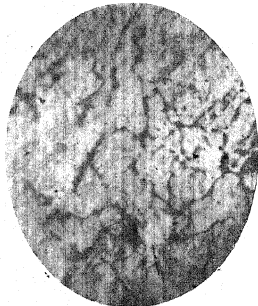


FIG. 24.



Grey Iron, Treated 40 Days at 950°. Fig. 23, from near Center of Section ; Fig.
24, from the Edge. (300 Diameters.)

FIG. 25.



Grey Iron, Heated to 1150° and Cooled Slowly. Showing Pearlite and Ferrite. (300 Diameters.)

FIG. 26.



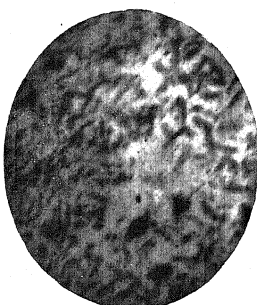
Grey, Held 3 Hours at 1160° and Cooled Slowly. (300 Diameters.)

FIG. 27.



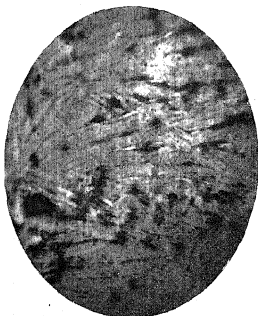
Grey Iron, Heated to 1000° and Quenched at 0° . (300 Diameters.)

FIG. 28.



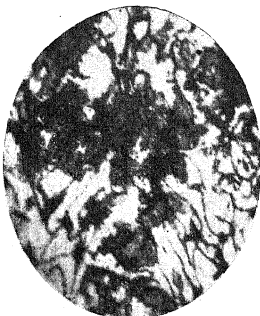
Grey Iron, Held 3 Hours at 1200° and Cooled Slowly. (300 Diameters.)

FIG. 29.



Grey Iron, Heated to 1300° and
Quenched at 0°. (300 Diam-
eters.)

FIG. 30.



Grey Iron, Heated to 800° and
Cooled Slowly. (300 Diameters.)

received the same treatment as the iron in Fig. 10, being heated 3 hours at 1100° C. and cooled slowly. It shows large grains of ferrite, surrounded by graphite. Scattered patches of pearlite were observed near the center and at the edge; otherwise the piece remained unchanged.

Fig. 27 is from a band around the outside of the section of a piece treated like that of Fig. 11, being heated to 1000° C. and quenched. This band is martensite; but the center was composed of ferrite and graphite.

Fig. 28 is from a section treated like that of Fig. 13, namely, heated at 1200° C. for 3 hours and cooled slowly. This section was composed mainly of large grains of ferrite with a fine network of pearlite. Near the edge was a thin band of structureless ferrite. From this band Fig. 28 was taken.

Fig. 29 is from a section heated to 1300° C. and quenched, like that of Fig. 14. The section was composed of ferrite and graphite at the center, and a band of martensite around the edge. Fig. 29 is taken from the latter portion.

Fig. 30 is from a section heated to 800° C. and cooled slowly, like that of Fig. 17. The structure of the section was little changed from that of the original grey iron; but pearlite had

begun to appear in the net-work about the grains, and in patches near the edge.

V. THE EFFECT OF HEAT ON THE PHYSICAL PROPERTIES OF WHITE AND GREY CAST-IRON.

Figs 31 to 36, inclusive, show the effect of heat upon the position of Ar_1

Specimens of the original white and grey iron, and specimens from all the long heats, were heated to $1200^{\circ} C$, and the cooling-curves were taken. The diagrams show: Fig. 31, the cooling-curves of the original white and the original grey and also of a specimen of 0.50-carbon steel; Fig. 32, the curves of the white and grey cast-iron from the 10-day heat. Figs 33, 34 and 35, the curves from the 20-, 30-, and 40-day heats respectively; and Fig 36, the curves of the white and grey iron, in which the points shown in the previous diagrams are plotted. In all these diagrams, the time of heating is indicated by the abscissæ, placed at intervals representing 20 seconds and divided to 10 seconds, while the temperature is indicated by the ordinates, which record the deflections of the galvanometer in the Le Chatelier apparatus, in tenths, similarly halved by subdivision. The exact correlation of these with the degrees of actual temperature has not been made, by reason of difficulties encountered in the calibration of the pyrometer. But the results graphically plotted in the diagrams are valuable for comparison among themselves, at least.

The table on page 758 gives the results of the tension-tests. In connection with this table, and the diagram, Fig. 36, it is interesting to note that the best strength-tests were obtained at or near the highest position of the recalescence-point. The grey iron shows this very well, and the white fairly well also. Since the increased proportion of pearlite probably accounts for the increased strength, we may perhaps say also that the general effect of pearlite is to raise the recalescence-point.

VI. SUMMARY OF RESULTS.

From the evidence set forth in this paper the authors believe themselves justified in drawing the following conclusions:

1 The malleable cast-iron process consists mainly of two steps (1) the breaking-down by heat of the carbide Fe_3C into

finely-divided temper-carbon and ferrite; (2) the slow oxidation of the temper-carbon, due to the formation of CO by the iron-oxide in which the iron is packed, and the subsequent combustion of the CO. That the carbide yields easily to heat is proved by Fig. 9, in which almost all the cementite is lacking.

On dissolving in a solution of double chloride of copper and potassium a specimen of white iron, so heated, we obtain a fine black amorphous residue as a result of the heating. This is temper-carbon. That this is subsequently oxidized to CO by the iron oxide in which the iron is packed, and that the CO escapes to be burned to CO₂, is proved by the chemical analysis which gave only 0.35 per cent. of total carbon in the outer oxidized ring of the iron, and by the blue flame seen burning at the box-covers.

2. The breaking down of the carbide occupies but a comparatively short time. This is obvious from Fig. 13, in which only a very little free cementite remains at the end of the 3-hour heat.

3. Graphitic carbon is removed from cast-iron with great difficulty. This is easily seen from the results of the long heats, in which a small black core of graphite and ferrite still remained unchanged in the grey cast-iron, even after 40 days' continuous heating.

4. Pearlite tends to form about segregations of graphite during long heating, and subsequent slow cooling. This is attested by the grey cast-iron sections from the long heats. In each case a well-defined ring of pearlite was observed about the black graphitic core of the center of the section.

5. A moderately long heating is beneficial to grey castings. This is shown by the improved strength-tests obtained from the 20- and 30-day heats of the grey cast-iron.

6. The great porosity of grey cast-iron, due to the removal of graphite by long heating, is the main cause of its weakness. This is easily seen from the fracture of any of the grey specimens after long heating. The surface was dull, showing that the fracture had taken place through the holes where the graphite had been.

7. It should be noticed that austenite occupies the same position in the structure of the white specimens quenched from

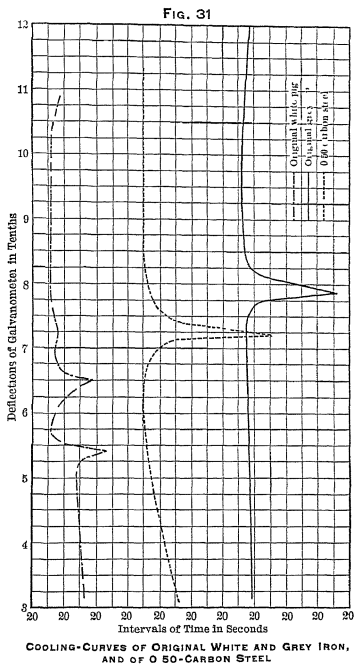


FIG 32.

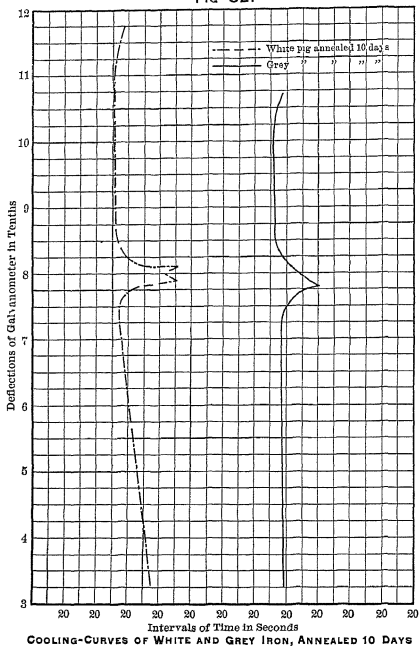
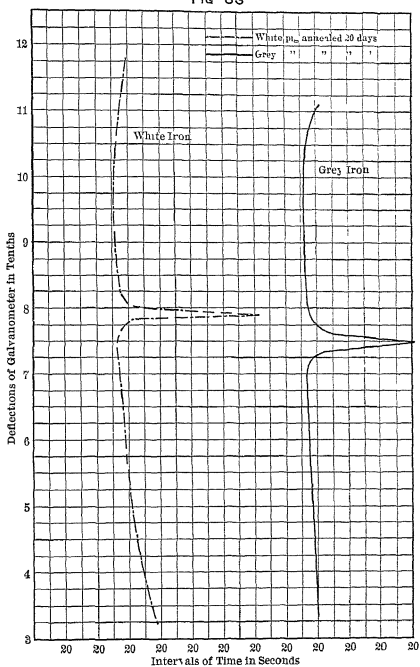
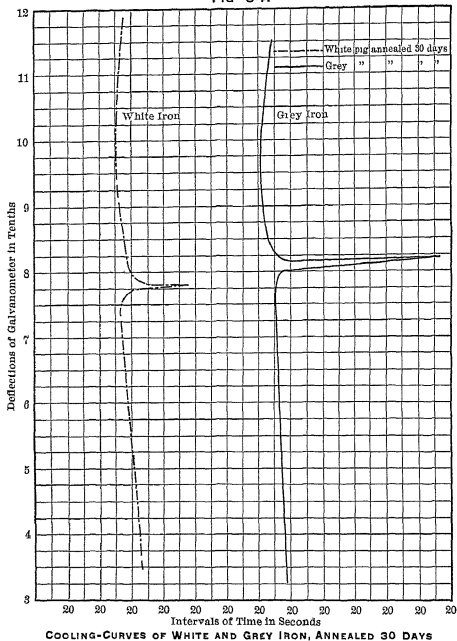


FIG 33



COOLING-CURVES OF WHITE AND GREY IRON, ANNEALED 20 DAYS

FIG 34.



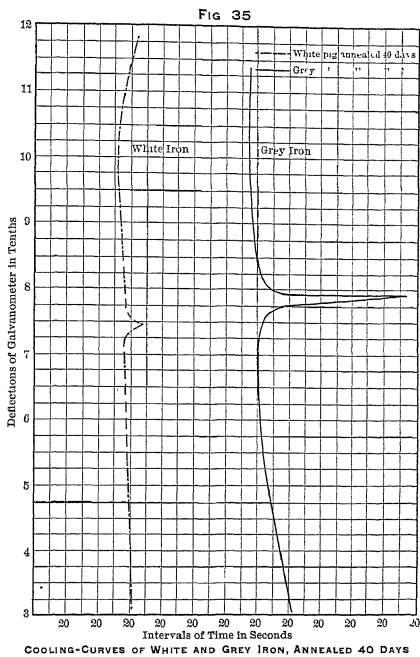


FIG. 36.

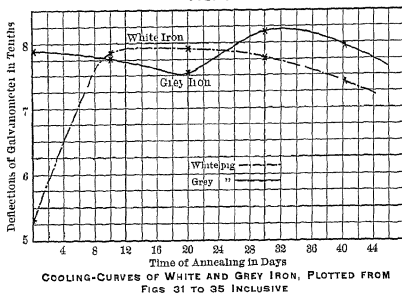


Table of Tension-Tests

Specimen	Elastic Limit Lbs Per Sq In	Ultimate Limit Lbs Per Sq In	Elongation Percent	Average Ultimate Limit Lbs Per Sq In
Original white iron*		{ 43,450 40,300 36,070 40,300 40,340 37,030		39,590
White iron Heated 10 days	{ 23,800 22,900	{ 39,940 38,300 22,620 20,000 22,160	4.0	39,120
Grey iron. Heated 10 days			1.1	21,600
White iron Heated 20 days	{ 29,750 28,790	{ 35,660 38,660 22,420 23,690	4.0	37,160
Grey iron Heated 20 days			0.9	23,050
White iron Heated 30 days	{ 29,450 31,070	{ 37,200 39,500 42,900	4.0	39,860
Grey iron Heated 30 days	{ 27,760 29,750 26,740	{ 37,700 38,000 32,090	4.5	35,930
White iron. Heated 40 days	{ 32,900 27,200 32,800	{ 39,200 39,700 40,500	4.5	39,800
Grey iron Heated 40 days		{ 23,400 27,900 24,300	0.9	25,200

* The original grey iron was entirely used up in experiments, and, unfortunately, was not tested for tensile strength before they were begun

high temperatures, as pearlite occupies in the white specimens cooled slowly from high temperatures

8. Pearlite is an element of strength This is obvious from our strength-tests for the 20- and 30-day heats on grey cast-iron, and more especially from the well-known high tensile strength of 0.80-carbon steel, in which pearlite composes the whole mass.

9 Ar₁ seems to be lowered by the presence of much combined carbon, as in the case of white iron This is well shown by the cooling-curve in Fig 31.

The authors here wish to acknowledge their indebtedness to Prof. Howe for his constant advice and supervision of the work here set forth, and also to thank Messrs Isaac Johnson & Co. for their great kindness in permitting the long experimental heats to be made in their furnaces.

An Occurrence of Limburgite in the Cripple Creek District

BY E A STEVENS, VICTOR, COLO

(Canadian Meeting, August, 1900)

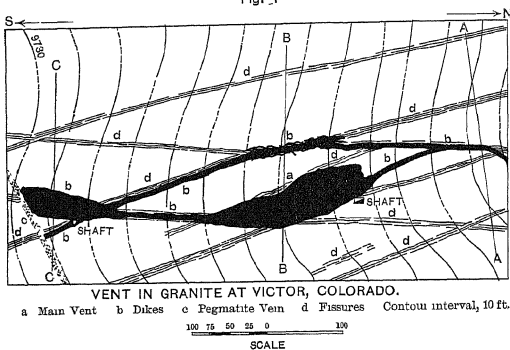
In a low and gently sloping ridge extending some 1500 ft. southward from Squaw Mt., and now covered by the buildings, or crossed by the railroads and streets, of a portion of the city of Victor, there is an ancient volcanic vent or crater, which exhibits one of the most interesting phenomena of the great upheaval and volcanic disturbance that built up the hills of the famous Cripple Creek gold-field—of the period when mass was piled on mass to form the mountains and foothills, when fissures and craters opened, and lavas, welling up, overflowed the surface, until, finally cooling, they effectually choked their vents, thus forming many of the ridges that stand out in bold relief, and the dikes that seam the Continent.

This particular occurrence, though limited in dimensions, shows in miniature certain stages of the eruptions of Etna and Vesuvius,* Kilauea and Loa, and illustrates what was (with the exception of the penetrating dikes) the closing chapter of the early volcanoes whose emanations have contributed to the

construction of thousands of square miles of the highlands of both hemispheres, and, on the North American continent at least, have played an active part in the mysterious cycle of ore-formation and deposition. The rock here exposed is limburgite;* and the occurrence becomes doubly interesting, since this rock has not been positively identified in any other locality in the United States †

According to Prof. Kemp, and as indicated by the analyses, limburgite is closely allied to the nepheline-basalt of this district—a rock also very rarely encountered elsewhere in this country

Fig. 1



The vent was formed at the intersection of two of the many fissure-systems cutting the granite in this locality, having respective courses of N. 15° W. and N. 5° E. (Fig. 1). The main vent has a rude lenticular shape, being about 50 ft wide in the center and 200 ft long.

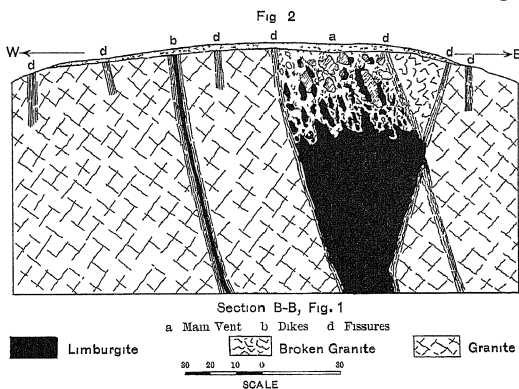
From its southerly end a dike extends some 250 ft. to the south, and at its northerly end another dike extends about 200 ft. to the north, where it pinches and entirely disappears. Also, a small lateral dike passes around the main body to the west, changing from one fissure to another, and forming a

* Microscopically determined for the writer in March, 1900, by Prof J F Kemp, New York

† G P Merrill, *Rock Weathering and Soils*, p 99

rough segment of a circle, uniting with the north dike 100 ft north of the main body (Fig 1)

The granite of this locality contains orthoclase as a principal constituent. The mica present varies in proportion to the degree of alteration that the rock has undergone. the fresh rock containing but little, while in that portion at or near the surface it reaches its maximum, the greater per cent. under the latter conditions being doubtless an alteration-product from the orthoclase.* A pegmatitic vein extends through the granite, forming a local limit of the limburgite southward, although



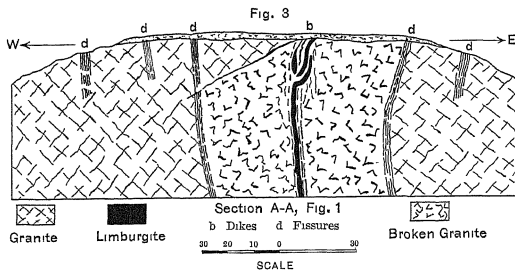
a dike, presumably of the same rock, of the micaceous variety known as "verite," cuts through the granite for several hundred feet about half a mile to the south, having a corresponding course and occupying approximately the same fissure

The only outcrop so far observed is from the vein c, Figs 1 and 4, to the point where the westerly branch leaves the main dike. Here the fresh rock reaches the surface, and from this point specimens were taken for analyses and determination (See Fig. 4)

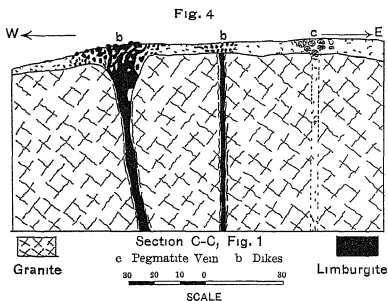
The local study of this occurrence was made at the point (Fig 2), a cut on the Florence and Cripple Creek R. R., re-

* Dana's *System of Mineralogy*, 6th ed., pp 320 and 631

ferred to by Mr. Cross* and Mr. Rickard;† in a cut on the Midland Terminal R. R (Fig. 3); in a 300-ft. shaft on the easterly contact of the vent. and in a 50-ft. shaft at the easterly edge of the outcrop (Fig 1)



There was no explosive outburst or violent ejection from this vent, although the upper portion of the filling exhibits considerable breccia, characterized by granite inclusions. As



the lava welled upward, a crust was formed as it approached the surface. The ebullition and pressure due to its hydrostatic head continually shivered the crust into fragments, and at the same time shattered and dislodged the granite along

* *Sixteenth Ann. Rep. U. S. Geol. Surv.*, part 11, p. 77.

† *Trans.*, xxx, 378 (1900), "The Cripple Creek Volcano."

the throat of the vent, much of which was precipitated into the opening, lodging in the rapidly forming crust, and, being difficult of fusibility, and buoyant by reason of its comparatively low specific gravity, was retained in the lava in its original condition, thereby producing the breccia now observed.

The broken condition of the granite adjacent to portions of the vent is very noticeable, and is fairly represented in Fig. 3. There is no doubt that this was brecciated in place.

With the exception of a small amount in the immediate vicinity of the outcrop, the limburgite is so completely decomposed and hydrated as to form a clay, speckled locally with mica and black hornblende, which crumbles away into a shapeless mass immediately upon exposure to the atmosphere. Its color under this condition, as seen on dumps and in shafts, is light bluish-gray to olive-green, except near the surface, where it has a reddish or yellowish cast, due to the oxidation of its iron-bearing mineral constituents. The dikes have a laminated structure, the laminae being parallel with the walls, and readily zeolitize along the joint-planes. The fresh rock is dark-green to greenish-black in color, breaks with a massive conchoidal, uneven fracture, and has a glistening surface. The structure is jointed, and, upon weathering, a rude ball-and-socket structure is developed. The most conspicuous mineral constituent is olivine, a hand-specimen of the rock showing fifty or more well-developed megascopic crystals of varying dimensions. Augite, magnetite, and an occasional crystal of mica, are visible under an ordinary hand-lens. The ground-mass, according to Prof. Kemp, is composed of fine augite crystals, set in a clear, colorless, isotropic base, either glass or analcite. In the particular locality of this vent, no ore has been discovered, but both north and south of it good ore has been found closely associated with this rock.

In the opinion of the writer more extensive petrographical investigation in this district will prove beyond doubt that much of the rock now recognized as nepheline-basalt belongs to the limburgites.

This lava, being very easily fusible, more so than the feldspar-basalts, or even the nepheline-basalts of this district, seems to have been the residue after all the other dikes and rocks had cooled, filling openings, fissures and shrinkage-

cracks produced by contraction and subsiding volcanic disturbances. Very little energy seems to have been exerted in the process of intrusion; and the dikes cooled so rapidly as not to adhere firmly to the granite walls

Its structural characteristics and physiographic occurrences very closely resemble those of the nepheline-basalt, both being very erratic, easily deviated from one channel to another with no visible connection, and, from a large and strong dike, suddenly pinching and disappearing, never to reappear.

Pyritic Smelting in the Black Hills.

BY FRANKLIN R. CARPENTER, PH D , DENVER, COLO

(Canadian Meeting, August, 1900)

PYRITIC smelting, so-called, as practiced in the Black Hills is pyritic smelting only in the sense that Dr John Percy uses the expression in his "Metallurgy of Silver," where he describes a process for smelting dry silver-ores in connection with iron pyrites, to form a regulus

The ores treated by this process in the Black Hills are very siliceous, averaging about 74 per cent. of silica, from 10 to 20 of iron oxide, 4 or 5 of alumina, and from 2 to 4 of lime.

In 1889, while Dean of the South Dakota School of Mines, I took up the question of their smelting. There were neither copper- nor lead-ores in the Hills; hence pyrite and pyrrhotite, of which there are large deposits, were employed to form a regulus. This mixture of pyrite and pyrrhotite, besides being absolutely barren of gold and silver, carried an average of 30 per cent. of silica. The only basic material available as a flux for the great excess of silica in the ores and in the pyrite was a dolomitic limestone. Moreover, the local coke gave 24 per cent of ash, 60 per cent. of which was silica—as unpromising a set of conditions as can well be imagined.

We had before us the examples of Mr. W. Lawrence Austin, of this Institute, who had experimented at Toston, Montana,*

* *Trans* , xvi , 257

and of Dr. Bartlett, now of Cañon City, Colorado. The whole literature of the subject was studied, and the situation at Kongsberg, Norway, seemed to be nearest our problem, but at all places where pyritic smelting was followed, one factor stood out prominently—the slags were always very siliceous, carrying about 50 per cent of silica. We could not reduce them to any very definite formulæ. They did not resemble any of the typical lead-smelter slags, nor did they always hit the oxygen-ratio of any definite or recognized silicate. The best slags for the process were apparently those which, as Kerl expresses it in his *Metallhutenkunde*, approached a bisilicate ratio. The slags which we found best for our material approached a bisilicate ratio, if alumina was figured as an acid (as is done at Mansfeld), but were more nearly the sesqui-silicate if alumina was considered as a base. Table I. gives the widest variations of slags made during my administration. I have also calculated the oxygen-ratio.

TABLE I.—*Analyses of Deadwood and Delaware Slags*

Date	SiO ₂	FeO	Al ₂ O ₃	CaO	MgO	Oxygen in Acid	Oxygen in Base	Silicate Degree	
								RO	SiO ₂
Usual Slags Made with Dolomitic Limestone									
Jan 4, 1898	50 6	16 3	2 3	18 3	11 9	1 84	1	1 09	2
Jan 29, 1898	47 5	16 8	4 9	18 7	11 8	1 57	1	1 27	2
Feb 17, 1898	45 7	17 6	6 1	17 9	10 1	1 53	1	1 31	2
Dec 5, 1898	49 1	15 0	4 2	18 47	10 6	1 76	1	1 14	2
July 14, 1899	48 0	13 0	5 4	20 0	12 9	1 57	1	1 27	2
Sept 9, 1895	49 0	11 11	5 86	22 6	12 04	1 58	1	1 26	2
April 23, 1896	47 5	9 64	7 00	22 6	9 10	1 63	1	1 23	2
Experimental Slags Made with Pure Limestone									
July 24, 1894	51 6	19 50	5 83	17 1	3 2	2 08	1	0 96	2
July 31, 1894	48 1	26 91	9 10	11 4	1 9	1 79	1	1 11	2

In Table I, the slags given under date of July, 1894, were made in an experiment with pure limestone. They were not so satisfactory as those made with dolomite. Their oxygen-ratio probably gives the real reason.

It was seen very early in our experiments that iron for flux was out of the question, and that, save the little that the ores carried, we must rely upon lime and magnesia as bases. I was

acquainted with the Mansfeld slags, in which the iron sometimes falls as low as 4 per cent., while the alumina may reach 15. In Table II, analyses of the Mansfeld slags are given for the purpose of comparison.

TABLE II.—*Analyses of Mansfeld Slags.*

	Cu	SiO ₂	FeO	Al ₂ O ₃	CaO	MgO	Oxygen in Acid	Oxygen in Base	Silicate Degree	
									RO.	SiO ₂
1	0 6	50 0	8 7	15 6	20 3	4 4	1 59	1	1 25	2
2	0 3	47 6	4 7	14 8	18 4	6 7	1 65	1	1 21	2
3.	0 25	53 8	4 4	4 4	33 1	1 70	2 18	1	0 92	2
	0 3	48 47	4 64	17 0	23 2	2 2	1 56	1	1 23	2
	0 3	46 4	2 77	16 52	21 51	0 85	1 66	1	1 20	2
	0 75	48 2	10 75	16 35	19 3	3 2	1 52	1	1 32	2
	0 2	48 4	5 89	18 17	19 5	8 02	1 33	1	1 43	2
	0 3	46 8	7 21	17 64	19 15	3 68	1 48	1	1 35	2
	0 3	57 4	7 47	7 83	23 4	0 87	2 47	1	0 81	2

NOTE.—At Mansfeld Al₂O₃ is figured as acid I have here figured it as a base in order to compare these slags with mine

I have figured the alumina as a base, as we always did in our work at Deadwood. With the Mansfeld slags before me, and the knowledge that, in iron-smelting, slags (cinder) are made in which there is not—intentionally at least—any iron, I was not discouraged over the slags. I had before me the work of Percy and Smith upon silicates, and their methods of experimenting with crucible-charges. As I was restricted to a siliceous ore of even composition, barren pyrite and magnesian limestone, I set myself to work to see what slags I could make most easily and profitably of these materials. I mention the method of experimenting, as it may, some day, be useful to others.

At this time there were associated with me, at the Dakota School of Mines, Dr. H. O. Hofman, now of the Mass. Inst. of Technology, and Dr. W. P. Headden, both of whom made valuable suggestions. The actual experimental work, which was long and tedious, was done under my direction by Mr. Theodor Knutzen, then a laboratory-assistant at the School of Mines, and for years connected with the smelting-works afterwards erected at Deadwood.

My idea was to take certain quantities of ore and limestone, and of pyrite, raw and roasted, and melt them together in a

crucible, after the manner of Percy and Smith, until I had determined the most fusible and desirable charge, as well as the most profitable, that could be made from these constituents. We used Hessian crucibles about six inches high, and an ordinary crucible-furnace. The material was finely ground, and many charges in varying proportions were tried, the endeavor being always to use as much ore and as little limestone and pyrite as possible. We added carbonaceous material to the crucible-charges, usually in the form of wheat-flour, so as to imitate as nearly as possible the action of a blast-furnace. After some experimental work, it was found that a charge composed of 40 per cent siliceous ore, 45 of magnesian limestone and 15 of raw pyrite gave a clean fluid slag, and a matte button at the bottom of the crucible carrying practically all the gold and silver, thus getting the results which, according to Bloxam, are obtained from the smelting together of lime, quartz and pyrite, at Zalathna in Hungary. These slags were analyzed, and attempts were made to deduce formulæ for them. The only noticeable feature was that the slags were high in silica and (though made without the use of copper) were free from gold and silver, or nearly so.

Dr Richard Pearce has shown that pure iron sulphide does not dissolve gold, while the experiments of E. G. Spilsbury^{*} at the Mass. Inst. of Technology, in matting the auriferous sulphides of North Carolina, showed that gold could not be concentrated in an iron matte satisfactorily. I will refer to this later.

Having done so much with crucibles, the next point was to do the work in a large way. Six thousand dollars was subscribed, with which I bought a 36-in round water-jacket furnace, a blower and engine and boiler, and seven car-loads of West Virginia coke, and erected an experimental plant, the so-called "baby smelter."

The charges which had worked best in the crucible-experiments were tried, I confess, with much anxiety; for my lead-smelting friends, with scarcely an exception, predicted failure and dire disaster. The first slags were duplicates of the experimental ones, and the furnace ran as smoothly as at any sub-

^{*} *Trans*, xv., 767

sequent run. I made a car-load of iron matte, carrying about 12 oz of gold, 60 oz of silver, and no copper, took it to Omaha, sold it to the smelter there, and returned to the Hills with the *argumentum ad hominem*, the cheque in hand.

The work in the crucibles was never much modified. The slags from the blast-furnace, however, while fairly clean, were not so notably so as in the crucible-experiments; and this led me to believe that a reverberatory furnace would possibly have done better work, as it would more nearly have imitated the crucible-experiments. It is said that when this raw-smelting was practiced at Freiberg, the reverberatory was preferred. We found it advisable to use somewhat more pyrite in our blast-furnace work than had been found necessary in the crucibles.

The "baby" or experimental plant was operated for several months, when it was decided to build a larger plant upon the same lines. Our first Raschette furnace was but 84 in. long; the next ones were 120 in., and the last furnaces erected were 144 in. long. Different degrees of bosh and of width were experimented upon. We found 36 inches about the best width.*

For many months the charge remained siliceous ore, barren pyrite and limestone. The first change was the substitution of Homestake stamp-mill concentrates for a part of the barren pyrite; and after several years the barren pyrite was replaced by copper-sulphide ores from Butte, Montana. The Homestake concentrates gave rise to large quantities of flue-dust, which in time became very annoying. All attempts at briquetting the concentrates, even with costly presses, failed. The problem was finally solved by re-smelting the flue-dust in large reverberatory furnaces, and adding the resulting low-grade iron-matte to the ore-charge of the blast-furnaces.

During our experimental work, I made one experiment in briquetting the concentrates that promised success. I bought a tank of the so-called "sugar-waste" of the sugar-refiners. It is a coarse molasses. I mixed up the concentrates with it and water, as a mason mixes mortar. When it was allowed to dry, it gave good results, but the plant smelled like a candy-factory,

* Fig 1 is a view of a still more recent furnace, designed and built under the writer's direction for the treatment of Cripple Creek ores by the Rocky Mountain Smelting Co., at Florence, Colo. The hearth is 36 in. wide by 180 in. long.

and apparently all the flues in South Dakota came down to investigate. The sugar-waste was not only cheap and did the work, but it also added carbonaceous fuel to the furnace as well. I believe the idea is well worth following out

Our practice, as at Mansfeld, where the ores also consist of earthy minerals low in iron, gave rise to "sows" or bodies of metallic iron. At Mansfeld these sows were formerly sold in England at the price of pig-iron. The ores at Mansfeld carry no gold, and these iron sows do not take up the silver. Had we been smelting only silver- or copper-ores, we might have disregarded them; but owing to the gold in our charge, and the affinity of metallic iron for it, these sows were our richest product. In time they came to replace the brick in the furnace-hearths and foundations. They were virtually blocks of solid metallic iron, weighing from 20 to 40 tons, and carrying sometimes 20 oz. of gold per ton. It was extremely difficult, as well as very expensive, to break them up, but we formerly accomplished this by boring holes with a ratchet-drill and repeatedly "shooting" them with dynamite, as many as fifty shots being sometimes required to break open the larger masses.

This was repeated until pieces of 100 or 200 pounds' weight were thus obtained. Sampling them was out of the question, but I made arrangements to have them smelted by the Omaha and Grant Co., which treated them with a lead sulphide carrying no gold. As our sows carry little or no silver, the bullion obtained by this process was kept separate, and sampled alone, to the entire satisfaction of all concerned.

One day I found an account of the method formerly employed by the Detroit Copper Co. in treating large masses of native copper, which was to place them upon the hearth of a reverberatory furnace and smelt them down with pyrites. I set about arranging one of our reverberatories with a removable top and large traveling crane, intending to do the same with my iron sows, when the foreman suggested the passing of them beneath the roof of the furnaces at such times as it became necessary to rebuild the flues, which would save altering the roof. The first time a flue came down we placed 40 tons of "sow" or metallic iron upon the hearth, charged the furnace with raw pyrites and copper-ores, and fired the furnace. At the end of

three days there was no sow in the furnace, nor was the hearth in the least injured, and several hundred ounces of gold had been recovered at mere nominal cost.

The slag and matte at Deadwood run together from the end of the furnace into a fore-hearth, either 3 by 5 or 4 by 4 ft. in size, and 2 ft deep, where the matte settles in the bottom, while the slag overflows into large slag-trucks. This fore-hearth is upon wheels high enough to run a matte-pot under its tap-hole. As fast as the matte accumulates, it is tapped from the bottom of the hearth into a pot. The fore-hearth is lost, usually by the accumulation of metallic iron or "sow," that raises the bottom above the tap-hole. These fore-hearth sows are identical in composition with those formed in the interior of the furnace, and are treated in the same manner as the furnace-sows. Owing to their small size, they offer no difficulty in the way of handling or breaking up. They usually weigh from 800 to 1000 lbs.

It was my theory that this metallic iron helped to clean the slags, and I did not really care to overcome its formation, but others have tried to do so. It was my theory that if the gold were not recovered in the sows, it would be lost in the slags, and here is, in my opinion, the solution of the question of clean slags in the use of iron pyrites free from copper.

The Deadwood iron matte was never a pure mono-sulphide, but a subsulphide carrying metallic iron, some of which could be separated as "metallics" by grinding and sifting. Traces of copper existed, while the matte always carried silver and arsenic. The traces of copper, silver and arsenic would, of course, take it out of the experiments of Dr. Pearce, to which reference is above made; but to my mind it was the metallic iron which cleaned the slags.

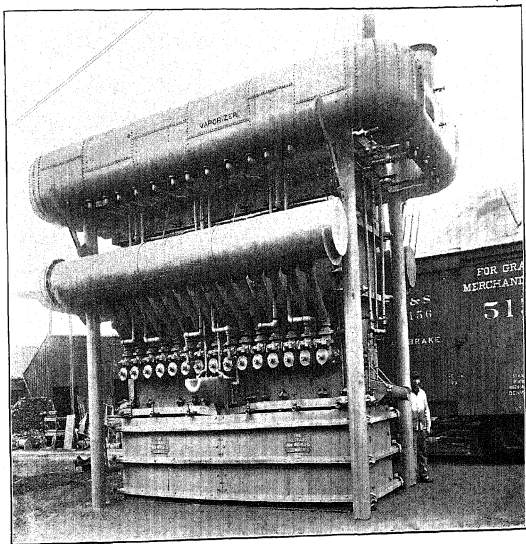
In a discussion of this question before the Colorado Scientific Society, it was remarked that if Dr. Carpenter would add more pyrite, he would avoid sows. It is a question whether, with our slags, this would be the case. At Kongsberg, where pyrite is added to the smelting as we added it at Deadwood, Samuelsen found that an increase in pyrite meant an increase in the metallic iron so reduced.* This was our experience at Deadwood. The formation of sows could be lessened, however, by cutting down the amount of coke used, and thus lessening

* See Crookes and Rohrig's English edition of Kerl's Metallurgy, vol 1, p 225

the reducing-action of the furnace. As this invariably meant an increase in the amount of gold lost in the slags, I aimed always to make some "sow."

Before it was possible to obtain copper, it was Mr. Knutzen's idea that it paid to add waste metallic iron to the charge, purposely, to make sure of the presence of metallic iron in the furnace.

FIG. 1.



Blast-Furnace of the Rocky Mt. Smelting Co., Florence, Colo.

I believe that a process for smelting the Siberian black sands, so that the gold might be recovered in metallic iron, was once proposed. From our experience at Deadwood, I have not the least doubt that it would have been successful. Even after we obtained the copper-ores from Butte, the amount of "sow" was in no way diminished. At Mansfield it has been found impossible to prevent the formation of these sows, although there

they serve no possible purpose unless it be to collect the small traces of nickel and cobalt in the ores. As the pyrrhotite was known to be slightly nickeliferous, I often intended to have our "sows" tested for nickel, but never did so.

The percentage of matte made at Deadwood is very low, seldom exceeding 5 per cent. of the weight of the charge, and formerly sometimes fell to 2 or 3 per cent.—and here I wish to note a peculiar experience. Before the use of copper, we could not always control the percentage of matte to be made. Sometimes almost the whole of the iron would go into the slags, and no matte would be made. At such times one would expect that the slags would carry the whole of the gold, but such was not the case. They were not noticeably more foul than at other times. I note one run of eighteen hours without matte, while it was common for hours to pass with little or no matte appearing. "Sow" was doubtless formed, but if so, it remained in the furnace, and with it the gold.

In the Altai mountains, where pyritic smelting is practiced (I use the term "pyritic smelting" always in the sense in which Percy first used it), the matte frequently falls to 2 or 3 per cent.^{*} We found the matte, however, much richer than usual, and I have made iron matte at such times exceeding 25 ounces of gold per ton. I am strongly of the opinion that, if the reduction of iron can be controlled in this form of smelting gold-ores, copper may be disregarded, especially when it is handled at a great loss, as at Deadwood.

Many persons have supposed that these high-silica slags are made only at a high formation-temperature. Prof. Hofman, in a most valuable paper,[†] has recently investigated the temperatures at which certain silicates are formed. In one series he gives the result of the addition of silica to the ordinary slag of the lead smelter. He adds silica by regular steps, and plots the result in a curve. The formation-point from 0.5 to 1.25 silicate-degree shows hardly any variation. The slags are formed at about 1180° C. The formation-temperature then falls off rather rapidly until the bi-silicate (2) is reached, and then less rapidly to a point half way between the 2½ and the tri-silicate

^{*} B. & H. Zeitung, 1886, vol. xlv, p. 177, footnote

[†] Trans., xxix, 682

(3). After the tri-silicate, which is formed at a much lower temperature than the mono-silicate, the curve rises very rapidly. At the basic end, however, the slags, he says, are very fluid, and melt down rapidly, while toward the acid end they melt down rather slowly and are far from fluid, notwithstanding their low formation-temperature

Again, in the replacing of lime with magnesia, the formation-temperature rises rapidly until one-eighth of the lime has been replaced with magnesia, then it falls until one-fourth has been replaced; then rises until one-half has been replaced, and suddenly falls until five-eighths have been replaced, and then rises rapidly until the whole of the lime is replaced, where it reaches a formation-temperature too high for metallurgical work

The curve, after the addition of magnesia, while it falls at two points rather low, at no time reaches the line of the basal or normal lime-iron-silicate.

That the same or a similar curve would be obtained if a different percentage of silica were used, as for instance in our Deadwood slags, is probable, but the use of magnesian limestone for our slags was preferred to the pure limestone. Nothing like a scientific attempt was ever made to determine the formation-point of our slags, hence I cannot say that they were less fusible than they would have been with all lime and no magnesia. They did seem more liquid, and certainly less magnesian limestone was required for the same work. This was due, of course, to the lower combining weight of magnesia. One part by weight of silica to form a bisilicate slag requires 0.93 parts of lime, but only 0.66 parts of magnesia.

Again, the Hofman curves show that the formation-temperature falls when lime is replaced by alumina. It falls below the line of his basal silicate until as much as three-fourths of the lime has been replaced by alumina. The slags, however, were very viscid. Now if magnesia raises the formation-point above the normal, and alumina lowers it, the net results might be, in our slags, not only to cancel each other's effects, but to give a more fluid slag, owing to the multiplication of bases, which in a general way is known to have that effect.

In pyritic smelting the slags must possess distinct characteristics—even if accomplished at the sacrifice of other points

First. They must be of low specific gravity, owing to the low specific gravity of the matte, that a perfect separation may be had by gravity. The high silica, lime, alumina and magnesia, and low iron, tend to bring this about. Second. In order to have time for the matte to settle out they must not chill too quickly. It is desirable, therefore, to form a slag which will remain fluid as long as possible. The low formation-points of the high-silica slags tend, I think, to aid this.

Before the appearance of Prof. Hofman's paper the peculiarities of slags were known only in a general way, and, speaking for myself, I knew more from the work of Percy and Smith than from any other sources. Percy did not, however, do more than to make mixtures and melt them in crucibles and note the results. In determining what silicates I could make at Deadwood, I simply followed the Percy-Smith methods; but by the aid of Prof. Hofman's paper it is now possible for the first time to predict what effects certain elements will have. In new work that I am doing for a matte-smelting plant at Buena Vista, Colo., and another for Cripple Creek ores, I have found this paper of great value.

In our slag-calculations we saved time by the continual use of Balling's well-known tables. The problem in our sort of smelting is very simple. We determined by means of the second table how much silica was fluxed by the iron, lime, etc., contained in the ores, subtracted it from the total amount to be fluxed, and then, by means of the first table sought how much limestone must be added to take care of the remaining silica. Of course a chemist can do all of this without the aid of tables, and moreover, since the publication of Roberts-Austen's work and of Hofman's "Lead," these tables are easily obtainable. That they may be still more easily had I give them here, feeling that their publication by the Institute will be appreciated.

If anyone doing this kind of smelting will keep his slags between 4RO , 3SiO_2 , and RO , SiO_2 , his troubles will be few; provided he has proper bases—*i. e.*, lime and iron, etc. If there is a trade-secret about matte-smelting for gold and silver, it is this only. The Balling tables will enable the most ignorant to observe these limits. The "typical" slags of Iles, Eilers, Schnei-

TABLE III — *Balling's Tables from "Compendium der Metallurgischen Chemie"*

One Part by Weight of Silica Requires	Parts by Weight of Bases	One Part by Weight of Bases Requires	Parts by Weight of Silica
<i>For Singulo-Silicates</i>		<i>For Singulo-Silicates</i>	
Lime	1 86	Lime	0 535
Magnesia	1 33	Magnesia	0 750
Alumina	1 14	Alumina	0 873
Ferrous oxide	2 40	Ferrous oxide	0 416
Manganous oxide	2 36	Manganous oxide	0 422
<i>For Bi-Silicates</i>		<i>For Bi-Silicates</i>	
Lime	0 93	Lime	1 070
Magnesia	0 66	Magnesia	1 500
Alumina	0 57	Alumina	1 747
Ferrous oxide	1 20	Ferrous oxide	0 883
Manganous oxide	1 18	Manganous oxide	0 845
<i>For Sesqui-Silicates</i>		<i>For Sesqui-Silicates</i>	
Lime	1 24	Lime	0 803
Magnesia	0 88	Magnesia	1 125
Alumina	0 76	Alumina	1 310
Ferrous oxide	1 60	Ferrous oxide	0 625
Manganous oxide	1 57	Manganous oxide	0 633

der, Raht, Hahn, Page and Livingston may be left as guides for the lead-smelters, who have need of them by reason of a widely different problem. To the matte-smelter they are not only useless, but confusing, and, I believe, often the cause of failure. With the iron matte low in copper, it is immaterial whether a little more or less iron goes into the slag; the resulting matte will carry the gold and silver in any case. The smelter in this line is not concerned with problems relating to the scorification of copper and lead.

REFINING AND DISPOSITION OF THE MATTE.

With iron matte, or matte very low in copper, there exists usually no problem, for it can be sold to the lead-smelters. With high percentages of copper in the matte, however, there is a difficulty. It carries usually too much gold for the ordinary copper-refineries, and too much copper for the lead-refineries.

At one time, about 1892-93, we had a difficulty in disposing of our matte. We erected a lead-furnace, bought lead-ores, and crushed and added the matte raw to the lead-charge. I found that the matte gave up nearly the whole of its gold to the lead. It still contained much silver. This matte was very different

from the "first matte," and for want of a better name we called it after the Germans, "herd-rohstein" (hearth matte), and added it to the matte-smelting charge, but owing to its containing lead, this treatment had not much success, as the lead was lost. The resulting bullion in the lead-process—very high in gold—was sold to the lead-smelters. Fearing that they might decline to buy this, also, we erected one very large cupel, and two smaller ones, all of the English type, intending to cupel the bullion and add the resulting litharge to the lead-process. The whole process was borrowed from pyritic smelting as it is practiced in Kongsberg and in Russian Siberia, save that I used an ordinary American lead-smelting furnace and English cupels. The process, except as to the loss of lead in the matte-furnace, was promising, and, in the favorite language of the patent-right man, "continuous." The "first matte" went into the lead-furnace, the second or hearth-matte back into the matte-furnace. The lead-bullion went to the cupels, and the litharge back to the lead-furnace. I do not know how this experiment would have ended; for our difficulties with the lead-smelters were adjusted, and our relations with them ever afterwards remained of the most pleasant character.

The idea of refining, however, continued with me, and in connection with Mr. Arthur Howe Carpenter, I made many experiments, sometimes original, but more often after the lines laid down by the old metallurgists, who seemed to have covered, in theory at least, about everything. The most satisfactory process, and the one I should have followed had I remained at the works, was that laid down by Jars (I think in 1784) and quoted by Percy in the first edition of his *Metallurgy*. Afterwards it was patented by the Vivians and others, and forms the first step, at least, of the Argo process. It will be remembered that our process was mainly for gold, and that copper-matte so high in gold was not desired by electrolytic copper-refiners. Any process that would take out the gold and other "impurities" would fit it for their process. The first step is the well-known copper-bottom process described for us by Dr. Pearce in his presidential address.* I proposed, not to try to separate the silver from the matte, but to proceed at once to the cop-

per-bottom process, which I thought might be performed either by the French "selecteur" method,* or as is now done at Argo.

The resulting product—high-grade copper-matte—having given up nearly all of its gold and much of its silver, could be blown up to blister-copper and sold directly to the refiners. The copper bottoms I granulated, oxidized and cast back into matte, and effected a second "selecting," similar in all respects to the first

This selecting process is not wholly successful unless the copper-matte is impure, a certain percentage of lead being necessary. This lead is, of course, concentrated in the first bottom or "selecting," so that this carries a very large percentage of lead. In the second selecting, this is so increased that the resulting bottom may be at once cupelled—often requiring little or no additional lead. In fact, the first bottom can be directly cupelled, with the addition of lead, if so desired, the coppery litharge being, as shown by Samuelson,† even more fusible than the purer litharge of the ordinary methods. In practice, six parts of lead to one of copper give very satisfactory results. The coppery litharge forms a product which can be treated by the lead-smelter, who has but to add it to his ore-charge—the lead going to the bullion, and the copper to the matte.

It is unnecessary actually to repeat the selecting-process in all its details upon the first bottoms as above described. Equally good results, with much less trouble, can be had by simply returning the first bottoms, or "plates," to a reverberatory furnace, with additional sulphide material, and running them over and over until they are sufficiently reduced in size for final treatment by cupellation with metallic lead. The resulting coppery litharge is easily reduced to metallic lead and matte by treatment in a small reverberatory or "softening" furnace, with galena, or iron pyrite; the lead may be used over and the matte is returned to the ore-smelting.

* Described in the *Eng and Min Jour*, October 22, 1898

† Percy, *Silver and Gold*, p 513

A Method for Obtaining the Volume of Small Drifts
and Working-Places, Where it is Impossible
to Use a Transit.

BY C. S. HERZIG, VIRGINIA, MINN.

(Canadian Meeting, August, 1900.)

In the *Engineering and Mining Journal* of Jan. 27, 1900, there appeared an article by Fred T. Greene, describing a method of measuring stopes by the use of strings, a clinometer and a tape.

In the early part of 1899 I had occasion to use a somewhat similar method, for the purpose of accurately ascertaining the volume of a very irregular drift connecting two mines. This drift was an important factor in a lawsuit for \$150,000, in which it was necessary to determine accurately the volume originally occupied by the material extracted from the drift.

While it is unnecessary to give all details of the controversy, some explanation of the conditions is required for a clear understanding of the following description. This drift was started by the "K." Co. from its workings, in about 7 ft. of ore, and headed toward the "G." property, the plan being to extract all the ore between foot- and hanging-walls, but to take out nothing but ore. As the "G." workings were approached, the ore-body became very irregular and much thinner. It was, however, very closely followed, and where the drift broke through into the "G." workings, the hole was only 11 inches high by 14 inches wide, or just about the size of a man-hole in a boiler. Thus, this connection-drift tapered sharply; and the very irregular foot-wall sloped toward the "G." workings, and entered them at a place where the stope was only about 3 ft. high, and the ground had already commenced to cave. It may be added that the ore-body was a nearly flat deposit of lead carbonate in limestone, the ore and gangue being quite soft.

I was called upon by the "G." people to make the survey

required to show the relation of this drift to their own workings. The opening into their own stope being so small, the roof being so low, and the drift itself being so irregular, it was quite impossible to get any satisfactory results with the transit in the ordinary way, because it was impossible to set up the instrument in any position outside the hole so that a new station could be located within, high enough to permit setting up the instrument. Upon consideration, I devised a method which gave us the volume very accurately and tied this drift to our other workings. What was sought was a series of parallel cross-sections, at a known distance apart, from which we could calculate the volume, as in railroad earth-work.

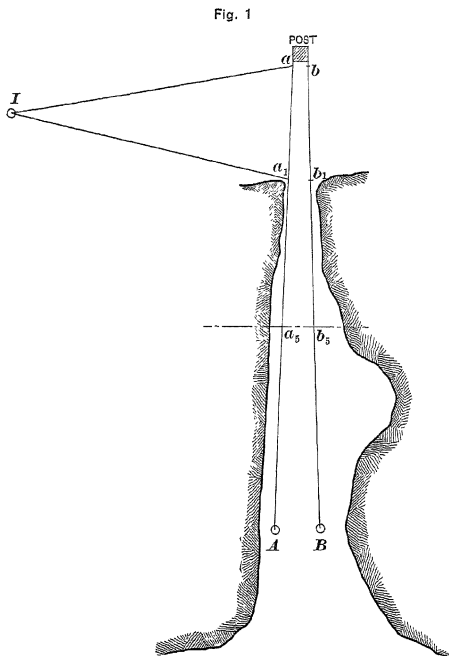
About 7 ft. in front of the 11 by 14 in. hole, and about square with it, stood a 12 by 12 in. post. A horseshoe nail was put in each of the two edges facing the hole. Two nails were now driven at A and B, Fig. 1, into the roof of the drift as far inside as was feasible, and strings were stretched between them (aA and bB , Fig. 1).

Then working up from the nearest station, a new transit station, I, was located as far away as possible, yet in such a position that all the string outside the hole was visible. From this station two points on each string (a and a_1 , b and b_1) were now carefully located and marked by means of fine piano-wire wound around the string; a and b were placed close up to the nails in such a manner that a line connecting them would make about the same angle with each of the strings; a_1 and b_1 were put as far along the strings as they were visible from the instrument.

Sighting at a , the distance Ia was measured and the vertical angle was read. The angle aIa_1 was next turned off and read, after which the distance Ia_1 was measured, and the vertical angle was read. Thus we had two sides and the included angle of the triangle; however, as a check, the distance aa_1 was measured. A similar operation was gone through with bIb_1 . In this manner the plane of the two strings was accurately located. The next step was to measure the distances aA and bB . This done, as many parallel cross-sections as were desired could be obtained with the aid of plumb-bobs, nails, fish-line and a tape. The locations of these cross-sections were selected in an

arbitrary manner, according to the irregularities of the drift, so as to obtain the precise volume.

The *modus operandi* was as follows: Let us assume that a sec-

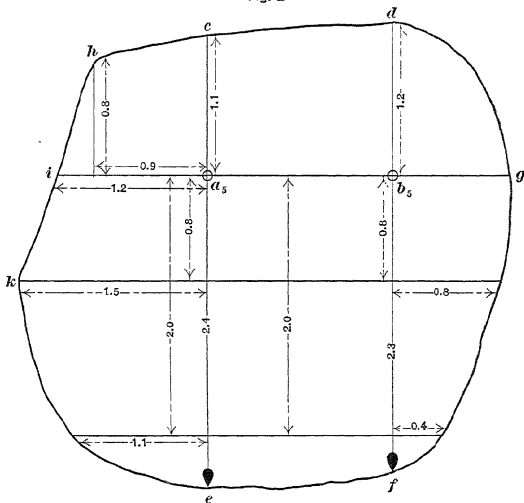


PLAN OF DRIFT,
SHOWING ARRANGEMENT OF STRINGS, Etc.

tion was desired at, say, $a_5 b_5$, Fig. 1. The distance from a to a_5 was measured along the string aA , say 16.3 ft.; the same distance, 16.3 ft. was laid off on bB from b , and each point was marked with a lead-pencil on the string, or by a string tied

around the point. Nails were then driven in the roof, directly over these points, in such a manner that plumb-lines suspended from them just touched the strings aA and bB at the marks, a_s and b_s . By this means, two points in the roof (c and d , Fig. 2) and two points in the floor (e and f) were fixed, by measuring the distances $a_s c$, $a_s e$, $b_s d$, and $b_s f$. It was found

Fig. 2



Page from Note-Book, Showing
CROSS-SECTION OF DRIFT AT POINTS a_s AND b_s , Fig. 1,
16.3 feet from a and b .

convenient in most cases to mark the points in the floor with nails.

Points g and i were next located by stretching a string across the drift, so that it just touched at a_s and b_s ; and then the distances $a_s i$ and $b_s g$ were measured. It will be seen that g and i are points in the plane of the strings Aa , Bb . Point h was

next located by making an offset of, say, 0.9 ft. from a_s toward i , and measuring vertically to the roof. Point k was fixed by measuring, say, 0.8 ft. down both from a_s and b_s and measuring across the plane of these two points, which is parallel to the plane of the two main strings.

As many points as are desired may be located in a similar manner, the main idea to be kept in view being that all measurements should be made vertically, or in a plane parallel to the plane of the two main strings.

A sketch of each separate section is made in the note-book and all the measurements are marked thereon; the sketch being labelled at the top of the page with the distance from the initial points a and b .

Having secured as many sections as are desired, the office-work to be done consists of a series of very simple calculations. From the work at the instrument, after the proper calculations have been made, the plan and elevation of the plane of the strings can be drawn, and from these the horizontal distances between the different sections can be scaled off; or, knowing the angle of inclination of the two strings, we can calculate the distances horizontally. Each cross-section can be laid off accurately with triangle and T-square, and the area can be calculated in the ordinary way.

Having calculated the areas of all sections, and knowing the horizontal distance between each two, the volume of each prism can be obtained by the formula:

Volume equals one-half the sum of the area of the two bases, multiplied by the altitude—the bases being any two adjacent sections, and the altitude the horizontal distance between them. The sum of all the volumes gives the total volume, up to the line across the two points A and B .

From our previous work we have the location of these points A and B ; to obtain the remaining volume, we set up our transit under either A or B and proceed to make cross-sections from our instrument in the usual way.

It should be added that the two sketches shown herewith are hypothetical, as I have no drawings of the real workings at hand.

The Evolution of Mine-Surveying Instruments.

BY DUNBAR D. SCOTT, HOUGHTON, MICH.

(See *Trans.*, xxviii., 679; xxix., 931.)

CONTINUED DISCUSSION.*

ALFRED C. YOUNG† (communication to the Secretary): Before the appearance of Mr. Scott's paper in these *Transactions* we were not specially interested in the investigation which he has started; but at his request we have endeavored to collect from musty records and the recollection of our old friends a brief chronicle of the progress made by this house.

As 3000 instruments were manufactured by us before any descriptive record was kept, and 2000 more before the record contained more than a statement whether the instrument was a transit or a level, and sometimes its size, we approach the task with timidity, trusting that the reader will bear the difficulties in mind, particularly as the writer's predecessors, from whom, no doubt, the information desired could have been obtained, have passed away.

Instruments for surveying were manufactured by David Rittenhouse, of Philadelphia, as early as 1760; but it was not until late in the first quarter of this century that there was any American market for an instrument outside of the ordinary surveyor's compass. With the advent of canals and railroads, and the more extensive development of the Pennsylvania coal-fields, arose a demand for surveying-instruments to meet problems in engineering beyond the limited field of the compass.

On May 1, 1820, in which year the practical mining of anthracite coal in Pennsylvania began, William J. Young, who had served his apprenticeship with one Thomas Whitney,

* SECRETARY'S NOTE.—This Discussion is printed here, instead of being reserved for the end of this volume, in order to maintain the order of the pamphlet publications (including the consecutive numbering of the illustrations), and to make the order of contributions on this subject correspond with that in which they will stand in the special volume, comprising the whole series, to be issued later (see Secretary's Note, *Trans.*, xxix., 1015).

† Conducting the establishment of Young & Sons, Philadelphia, Pa.

started in business on Dock Street, in Philadelphia. Recognizing the fact that compasses, or "circumferentors," as they were commonly called, were not equal to the demands made upon them, and that the English theodolites had too many parts liable to injury, were cumbersome and ill-adapted to transportation, Mr. Young commenced to plan an instrument that would permit horizontal angles to be taken independently of the needle, and allow "back-sights" to be obtained without reversing the telescope in its bearings.

In 1831 he introduced the first "American engineer's transit" (Fig. 60* of Mr. Scott's article). From that time to the present *all* improvements have been merely in the perfecting of details and the addition of attachments to meet special requirements—so well were the fundamental principles thought out by the inventor, even to such minor features as the placing of the verniers at one side of the standards, so as not to risk disturbance of the instrument while readings were taken.

In July, 1858, he patented the "shifting-tripod-head." By simply loosening the leveling-screws, the transit can be shifted a short distance in any direction after the instrument has been approximately set up. No improvement has been made in this invention since its introduction.

The first compound "long-center" transit was made for J. Simpson Africa, Esq., President of the Union Trust Company of this city, who, in a letter dated February 1st, 1899, says:

"I am reminded that the first long-center transit-instrument mentioned in your books was purchased by me November 11, 1853.

"My engineering records and papers being at my old home (Huntingdon, Pa.), the only information I can give now is from recollection. Through my instructor in practical engineering, Mr. Samuel W. Mifflin, I made the acquaintance of Mr. William J. Young, the founder of your house. One of my duties was to test, in actual surveys, transits that he had made for a railroad then in progress of construction. All these had short reversible telescopes, and verniers for the plates were *within* the compass-box.

"Needing in my own business an instrument with which I could measure angles with greater precision than could be attained by those mentioned above, I suggested to Mr. Young to construct for me a theodolite somewhat after the English model. He convinced me that a transit with a long center, wider plates than were commonly used, verniers outside the needle-box, and a long telescope, would meet my requirements, and be more satisfactory than a theodolite. This conference resulted in my giving him an order for the instrument you mentioned.

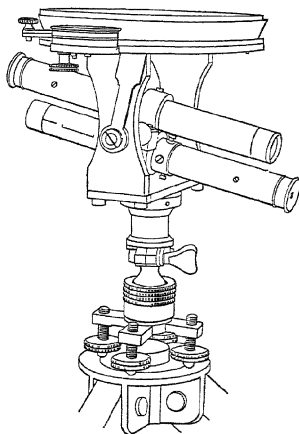
"I used it with great pleasure and satisfaction for many years in general engineering work, and especially in the laying-out of towns, and in defining disputed

* *Trans.*, xxviii., 744.

boundaries, where the greatest attainable accuracy was desired. Many years later I had another transit made at your establishment, built on the same general plan with the then modern improvements added. This instrument took the place of the one made in 1853, and is now in use by one of my sons."

As to the dates of the introduction of the various forms of mining attachments to engineers' transits, and the names of those who suggested these improvements, our early records supply but meager information. Fortunately, however, some of the instruments are still in existence, from which photo-

FIG. 92.*



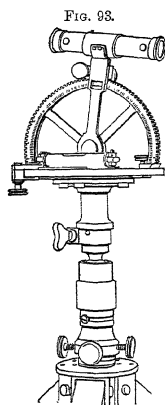
Bartolot's Mining Compass.

graphs have been obtained, leaving in doubt only to whom the honors may belong. The following list comprises mining instruments made by this house at various times, and not hitherto mentioned in this discussion.

Fig. 92 (our shop No. 3366) represents an instrument made in April, 1855, for a Dr. Bartolot, who seems to have lived in the anthracite coal regions of Pennsylvania. The instrument was intended only for magnetic surveys, so that the compass-

* The illustrations are numbered consecutively throughout all the contributions on this subject. Fig. 91 will be found in *Trans.*, xxix., 1014.

box was placed conspicuously above, where observations of the needle would be least obstructed. The compass was provided with what was then known as a "Nonius-plate"—a simple marginal indicator that marked off the degrees, and the larger subdivisions thereof, to be used in allowing for variation. I suppose Pedro Nuñez, the Portuguese mathematician, who lived in the first half of the sixteenth century, was the first to use this device, but Rittenhouse is said to have been the first to use the vernier for this purpose. The complete revolution of a telescope in a design of this peculiar kind was impossible; and the method resorted to, of using duplex telescopes for



Mulloney's Mining Dial.

forward- and back-sighting, makes this model, so far as we know, unique among mine-surveying instruments. The only other type at all similar is Mr. Hoskold's (Fig. 39*), which he was perfecting some two years later; but the methods employed in each case will scarcely permit a comparison. The duplex telescopes revolved about 20° from the horizon each way, upon a common axis, that could be adjusted for horizontality by means of the capstan-head screws shown in the figure just below the base of the standards; but their adjustment for parallelism could only be secured by the maker. The instrument was leveled by the ball-and-socket base, the four leveling-screws and the box-bubble at the side of the compass-box.

Fig. 93 (our shop No. 3448) represents a mining instrument made in October, 1855, for J. F. Mulloney. It is decidedly of English parentage, possessing the same rack-movement shown in Fig. 16,† and an arch much as it appears in Fig. 15.‡ The horizontal plates were maneuvered by the same kind of rack-work. But the most remarkable feature is the substitution of "Locke's sights" for the telescope. These sights are practically what are known to-day as Locke's hand-level, invented by Prof. John Locke, M.D., of Cincinnati, in

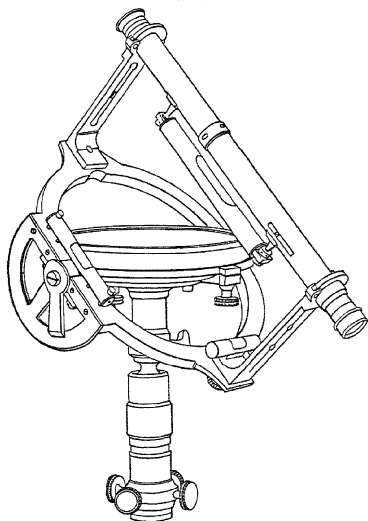
* *Trans.*, xxviii., 722.

† *Trans.*, xxviii., 696

‡ *Trans.*, xxviii., 695.

1850. I suppose Mr. Mulloney wished to use the sights for leveling purposes, and, as they did not permit accurate centering, he very wisely demanded that the arch be graduated and read by a simple index to only $\frac{1}{2}^{\circ}$. The base of this instrument is very tall, slender, and really an ill-proportioned type, though it was very common in those days. From the ball there extended down through the barrel a square shank,

FIG. 94.



The Smith-Hedley Dial.

upon the faces of which worked the opposing screws shown just above the tripod head. After clamping the ball and socket tightly, the instrument could be brought to a more perfect level by use of these screws. Two extra tripods with sockets for holding candles, as is common in Cornwall to-day, were furnished with this instrument.

Fig. 94 (our shop No. 3545) represents a modification of the Hedley dial, made in October, 1855, for Thomas Smith, of

Luzerne county, Pa., and bears the distinction, we believe, of being the first Hedley dial ever provided with a telescope, Mr. Stanley's instrument (Fig. 40*) not being made until 1874. The Smith-Hedley dial had within the compass-box a horizontal plate, graduated to read minutes, that was governed in its movements also by rack-work. The rocking limb was 10 in. long and provided with a side arc upon which grades as great as 70° could be observed before the limb came in contact with the base. In this particular, this style of base or support is superior to the Hoffman-Harden tripod-head used by Mr. Stanley, until he remodeled the rocking limb (Fig. 63†), so as to permit vertical sights. How-

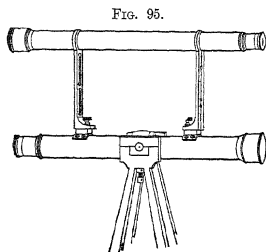


FIG. 95.
Petherick's Mine Transit with the First of Top-Auxiliary Telescopes.

ever, these instruments are out of date now in this country, though there was a time when they were widely used in railroad construction. It is from this instrument that compasses designed to give horizontal angles independently of the magnetic needle received, and still bear, the name "railroad compasses."

It was but a step in the line of progress to mount the telescope in Y's, as shown in Fig. 95, and attach it to the instrument shown by Mr. Scott in Fig. 34.‡ We believe that this was the first American top-auxiliary telescope, and that the opinion ascribed to Mr. Knight (*Trans.*, xxviii., 717) is not well founded. We are not positive as to the exact date of introduction, but we present in Fig. 95 what was doubtless the pioneer instrument of the top-auxiliary type, and as far as we have been able to determine, it was made for Mr. Wm. Petherick, Superintendent of the Copper Falls Mines, Mich., 1855-60, apparently from drawings furnished by him.

As first made, the auxiliary telescope was clamped on the main telescope about the same as compass-sights, but would never clamp in line with the main telescope. Then the uprights

* *Trans.*, xxviii., 723.

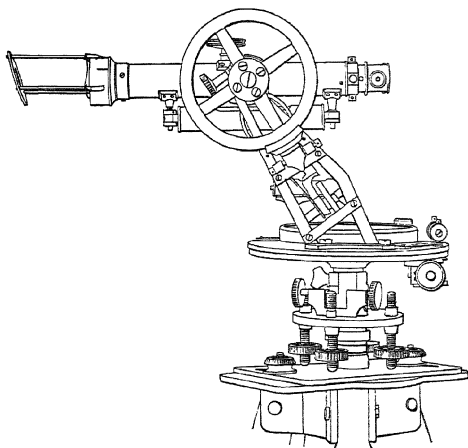
† *Trans.*, xxix., 939.

‡ *Trans.*, xxviii., 717.

were attached permanently to the transit-telescope, and the auxiliary only was made detachable, as well as reversible, "end for end" (somewhat as shown in Fig. 94); but in this form the uprights would get bent in the mines, and render the attachment useless. A hinged upright was then tried, similar to the folding compass-sight (Fig. 34, above cited), but the hinge-pin would wear, and the uprights rattle.

The writer's plan, introduced in 1891, is to mount the

FIG. 96.



McNaïr's Original Inclined-Standard Mine Transit.

uprights upon a base-plate, and attach it to the main telescope by "Y" bearings.

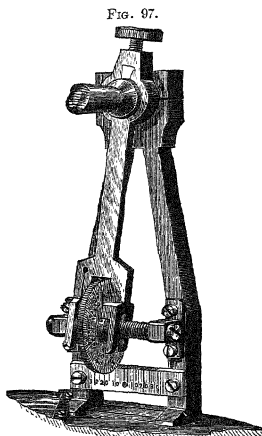
When Mr. Scott assumes* that the inclined-standard mining-transit came down through Seibert's solar, he is not entirely correct. As a matter of fact, the first inclined standards made by this house were made in July, 1854, for Alexander Roberts, of Hamburg, Pa. In the next year we made one of the same kind with long center, double verniers and telescope-level, but

* *Trans.*, xxviii., 725, 726.

no vertical arc, for the Philadelphia, Wilmington and Baltimore R.R., but we have no photograph or further description of these instruments. From this time on, no others of this pattern seem to have been made by us until that made in 1875 for Thomas S. McNair, then mining engineer for the Lehigh Valley Coal Company at Hazleton, Pa. It was at this time that our Mr. Thomas N. Watson, in the course of the argument, suggested the principle of the "hinged standards" by revolving a draughtsman's triangle on one of its corners. The

idea was rejected; but it seems to us now that if unusually large journals had been used and the adjustment had been secured as in the horizontal axis of the telescope, it could have been made to project correct alignments.

Mr. McNair's instrument is still in use, and is reproduced here (Fig. 96) from a photograph kindly prepared by that gentleman especially for this discussion. The credit for first having used this type in mining work is possibly due to Mr. McNair; but he modestly refuses to accept it without reserve, observing, "The ancients, you know, are said to have infringed on our inventions." Attached to this in-



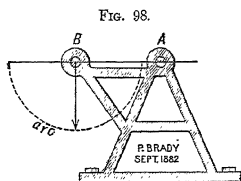
Young's Gradiometer.

strument will be noticed the style of gradiometer introduced by this house in 1872, the first, we believe, to appear in America. It is shown more in detail in Fig. 97. We use it still, for the reason that it is not so exposed as the other style, and is equally easy to read and manipulate.

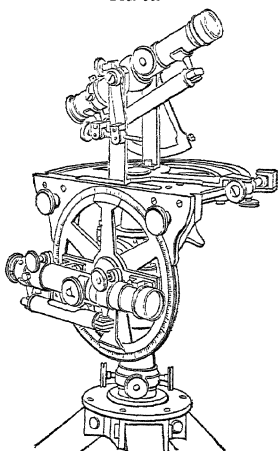
Of distinctively mining transits, there are probably more of the inclined standard type in use than any other, all objections to its eccentricity and "overhang" melting away wherever it has once been used. It has achieved this recognition without any special recommendation on the part of the makers.

From this time on, the desirability of combining the advantages of McNair's model with those of the concentric type began to occupy the minds of engineers. In 1882, Mr. Peter Brady, then connected with the Glendon Iron Co., Easton, Pa., suggested to the writer the advisability of designing a mining instrument (Fig. 98), substantially what is known to-day as the duplex-bearing mine-transit. It was pointed out to him that the structure, with all the necessary appliances, would be so cumbersome as to merit the present well-deserved name of "steam-engine;" that there would be great difficulty in keeping the bearings free from grit and in proper adjustment, and great liability of the changeable parts to injury; so, upon due consideration, the idea was abandoned.

In 1854, Edwin J. Hulbert ordered of us, as he has explained, an instrument (Fig. 99*) known then as the "Lake



Brady's Proposition.



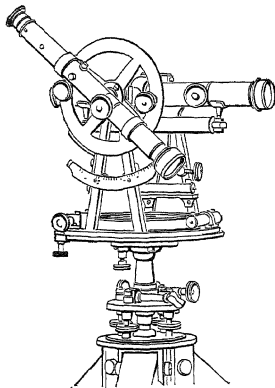
Hulbert's First Instrument.

Superior pattern." Figs. 99 and 100 show some features not clearly seen in the illustrations given by Mr. Hulbert. In Fig. 99 the upper plate was semicircular, 8 inches in diameter, reading by a single vernier to minutes. The vernier was in the clamping-arm or alidade of the upper limb, and was also provided with a small tangent-screw. The telescope was provided with a vertical arc, clamp and tangent-screw and loose vernier-arm, as

* Compare Fig. 90, *Trans.*, xxix., 1012.

introduced by Alfred Young in 1850. The side-telescope, having a level attached, was mounted on a free vertical circle, $6\frac{1}{2}$ inches in diameter, reading by two verniers to minutes; a clamp and tangent were also provided; all mounted on a compound ball-and-socket with leveling screws. Not many of these instruments were made. While seeming to fulfill particular requirements in the copper regions of Michigan, they were not favorites with the instrument-maker, on account of the peculiar

FIG. 100.



Hulbert's Original Side-Telescope Transit.*

shape of the plates, the contraction and expansion of which were apt to destroy the adjustments; and the absence of the needle was at that time a popular objection on the part of the engineer.

Fig. 100 shows what was probably the first side-auxiliary telescope attached to a mine-transit in America or elsewhere. It was made for Mr. Hulbert, from designs furnished by him, as he explains, in 1856. A full vertical circle was connected permanently with the axle of the transit-telescope. The

auxiliary telescope, which alone was detachable, was attached to the vertical circle by means of two milled-head clamp-screws.

Fig. 101 illustrates an improvement in Mr. Hulbert's pattern. The telescope is much shorter and larger in diameter, and is permanently connected with the full vertical circle, which is also made detachable.

Later, several methods were adopted to simplify the attachment of a side-auxiliary, one of which was a perforation of the horizontal axis large enough to permit the insertion of a spindle attached to the telescope (as shown in Fig. 28†). The objec-

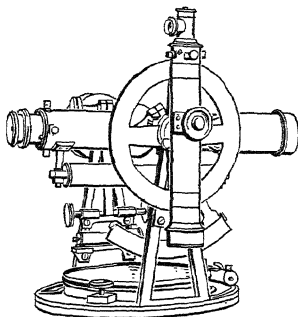
* The same instrument as the one of Fig. 91, *Trans.*, xxix., 1014.

† *Trans.*, xxviii., 712.

tion to this was that, unless the horizontal axis was made very heavy, it was weakened at a vital point.

Another method was to terminate the horizontal axis in an enlarged threaded hub beyond the outside of the standard and to screw the telescope on with a clamping-nut, as in Fig. 38,* but as the threads wore, the alignment of the telescope was destroyed; and while the parallelism of the two telescopes was not disturbed to any marked degree, the zero (level) points were, and it was necessary for the engineer to allow for this index-error, or insert a piece of tin foil between the hub at-

FIG. 101.



Improvement on Hulbert's Mine-Transit.

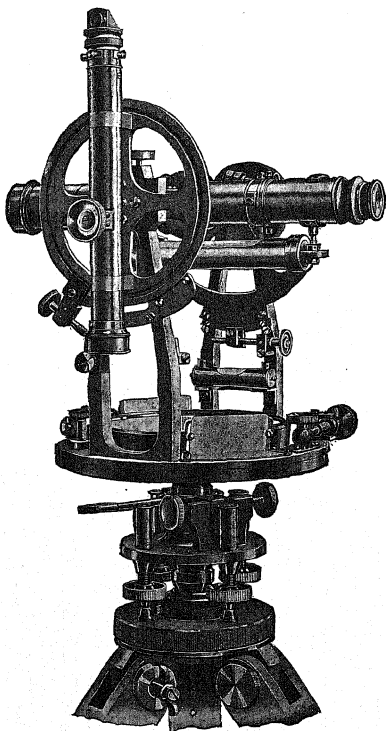
tached to the telescope and the side of the standards. Of late years it has been customary to add a tangent-screw or two opposing screws to remedy this objection.

Fig. 102, illustrating the style in use at present (1899), is taken from a transit made for use in the Kimberley mines, South Africa. The auxiliary telescope is attached permanently to the vertical circle (5 in. in diameter, and reading by a single vernier to one minute), and is provided with a clamp and a tangent-screw. The graduations are on the inside of the circle, to protect them from injury, and to facilitate the reading of the vernier. The telescope (non-extension, dust- and water-

* *Trans.*, xxviii., 720.

proof), 7 in. long, is furnished with a diagonal (prism) eyepiece and a reflector for cross-hairs (the latter not shown in the

FIG. 102.



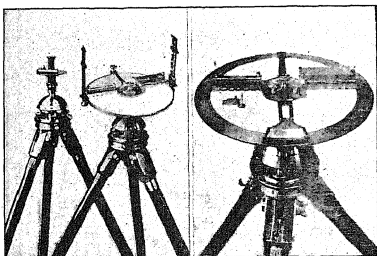
Young & Sons' Modern Mine-Transit.

figure). All the attachments, with the counterpoise, are detachable, and when they are not in use the engineer has still a complete transit, with all modern improvements, having a gradu-

ated plate $6\frac{3}{4}$ in. in diameter, level to telescope, clamp and opposing screws (not shown in the figure) and vertical arc.

FRANK OWEN, London, Eng. (communication to the Secretary): The following detailed description of the "Henderson Rapid Traverser," alluded to by Mr. Scott* and by Mr. Brough,† may be of interest. I am indebted for it to the courtesy of the inventor, my former teacher, Mr. James Henderson, M. Inst. C. E., of Truro, Cornwall, England. He previously in-

FIG. 103.



Henderson's Rapid Traverser.

vented the Henderson dial,‡ a circumferentor with four sights, described by Brough in his *Mine Surveying*, and by Stanley in his *Surveying Instruments*. The present account is based on a paper read by Mr. Henderson before the Mining Association and Institute of Cornwall in December, 1893. The illustrations, Figs. 103 and 104, are taken from the catalogue of Messrs. E. T. Newton & Son, Camborne, Cornwall, the makers of the Traverser.

The Rapid Traverser is a circular brass table of about 10 in. in diameter, mounted on a tripod-stand with the usual levelling-screws, and having a brass alidade or ruler that revolves around a fixed centre-pin, and that has at each end a vertical sight, capable of being replaced by an arc or quadrant when angles of considerable elevation or depression are to be measured. On the top of the table, a disk of enamelled zinc is securely fixed by small screws and nuts and by a central holding-down brass plate, over which the alidade freely passes. Rain or dropping water, or even washing with soap and water, will not obliterate the pencil-marks; yet hard scrubbing will remove them, and the disk can be used repeatedly.

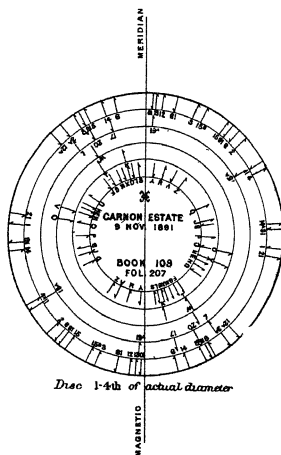
* *Trans.*, xxviii., 691.

† *Trans.*, xxix., 933.

‡ *Trans.*, xxviii., 695.

The surface of the disk has five concentric rings scratched or marked upon it by means of a pencil inserted in five small notches in the thick edge of the alidade, and held fast while the disk is revolved. The fiducial or feather edge of the alidade has corresponding marks, numbered and with a rectangular notch opposite each division, to allow the letter or number of each course or station to be marked on the disk. The concentric rings are to prevent the overcrowding of traverse lines in any one direction, and enable separate surveys to be made with the same disk without interference. The table carrying the disk can be firmly clamped to the tripod head, and the alidade to the table when required. The clamping screws for each are distinguished by a difference in form.

FIG 104



Disk of the Rapid Traverser in Use

In use, the fiducial edge should always be on the observer's right hand. After clamping the table and sighting the alidade, the direction is marked with a fine pencil-line drawn across the space between any two adjacent concentric rings. The leading direction is indicated by a single barb, or half arrow, at one end of the line, and the number or letter of the course is written within the notch cut in the edge of the alidade. For hilly ground, the sight at each end of the alidade is marked in degrees up to 25, and has a sliding-bar so fitted that by looking through the eyehole at the top of one sight and setting the sliding-bar on the forward object, the angle of inclination can be read and noted. Or, for greater accuracy, the quadrant can be substituted for the sights, and the angles read to minutes. The telescope attached to the quadrant revolves on a vertical axis, so that by revolving 180° to a mark made for the purpose, back sights can

be observed without shifting the alidade. In going from one station to the next, the Traverser is removed from its stand, and fixed, with the alidade still clamped, on the forward stand, and sighted back to the former tripod and clamped. Then the alidade is unclamped and a sight taken to the next station, or to any subsidiary station. It is recommended that three tripods be used in a traverse either underground or on the surface. The magnetic meridian can be taken at any convenient station by means of a trough-compass placed temporarily against the back of the alidade. The distances from station to station are measured separately, and are entered, as usual, in a note-book.

For plotting, the disk is removed from the brass table, and placed in proper position upon the intended map, with one or more meridian lines upon it, and is held firm by a weight or two. Then, with a parallel ruler, best a rolling one, the successive courses of the survey are transferred to the map. The disk becomes a protractor of great accuracy, and the plotting is more rapid than usual. The disk may be kept for future reference, or can be cleaned off by scrubbing with soap and water, or with india-rubber. If desired, the bearings can be read off rapidly, by means of an alidade moving about a pin in the centre of a protractor over which the disk has been placed.

The Traverser can be used either in mines or on the surface and for setting out railway or other road lines by chords of any length previously drawn on the disk, with the lengths thereof noted in the field-book.

Clearly, the Traverser is based on the plane-table method, and is really a goniograph or angle-drawer without any reading or booking of angles, but, unlike the plane-table, it is not used for plotting the survey in the field. The advantages claimed over other surveying instruments are 1 A great saving of time 2 Simplicity of construction, and consequently comparative cheapness. 3 Portability, and without liability to damage 4 Great simplicity in the subsequent plottings.

R. W. RAYMOND, New York City. A few additional notes may help towards the more complete elucidation of Mr. Scott's main subject.

Astrolabe—Reinhold* explains that the surveyor's astrolabe (in German and late Latin, *astrolabum*), the lower part of Fig. 105 (see also Fig. 83†), is properly a whole or a half-circle of brass, graduated, the whole circle to 360°, the half one to 180°, with a pair of fixed sights at the ends of the diameter, and with an alidade revolving about the center and bearing at the ends another pair of sights. The *Encyclopædia Britannica* (under *Navigation*) gives the simpler, older form of the astronomical astrolabe, as described by Martin Cortes in his book, *The Art of Navigation*, Seville, 1556, and copied in the upper part of Fig. 105. It is a polished circular plate of copper or tin, 6 or 7 inches in diameter, purposely weighty, so as to hang

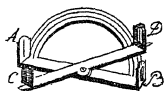
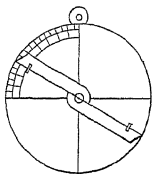
* *Geometria Forensis oder die aufs Recht angewandte Messkunst*, C L Reinhold, Muenster, 1781, 1st pt., p. 106

† *Trans.*, xxix, 986

steady and plumb by a hole at the top; and graduated to degrees in the upper left-hand quadrant, and some years later in both upper quadrants; and there is a pointer of the same metal, with two sights upon the "line of confidence," that passes through the center.

Reinhold further says that the astrolabe has later been enriched and improved with accessory appliances, as he illustrates by Fig. 106, showing one that he has found the most perfect AB is the whole circle divided into 360° , CD, the alidade,

FIG. 105.



The Astrolabe, Simplest
Forms the Upper, As-
tronomical, the Lower,
for Surveying

EF, sights high enough to see over the fixed sights GH. The telescope, JN, revolves about O vertically, with a spirit-level on top, and with the half-circle, MLK, joined below and read with the index L. The compass P rests on the alidade. The telescope QR, as well as JN, takes the place of the sights in the case of distant objects. It is plain that the instrument is essentially a theodolite, much resembling the instruments of Figs. 16 and 17,* except that the telescope is supported by a single central standard instead of two side ones, and the verniers are upon arms, or an alidade, instead of a plate.

Evidently, then, the word astrolabe had, in surveying, a very wide range of application, from the simplest semicircle with an alidade and two pairs of sights up to a theodolite with two telescopes, with verniers, or even with a compass

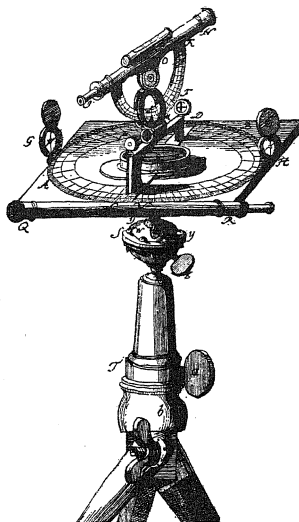
Zollmann's Disk.—Reinhold says† that Zollmann's disk, Fig. 107, is a round wooden board with a frame to enable paper to be stretched. There is an alidade, movable horizontally about a pin in the middle of the disk. The instrument is nearly allied to the plane-table, but resembles yet more closely Douglas's Infallible, of 1727,‡ and, like that, might be called in some sort a progenitor of Henderson's Rapid Traverser.

* *Trans.*, xxviii, 696, 698

† *Op cit*, p 137.

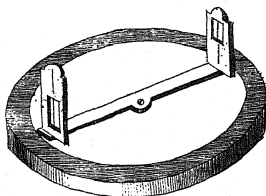
‡ *Trans*, xxix, 933

FIG. 106.



Reinhold's Best Astrolabe.

FIG. 107.



Zollmann's Disk.

Iron-Disk (Eisenscheibe).—Von Hanstadt* explains that the iron-disk (*Eisenscheibe*)† is so called, not on account of its ma-

* *Anleitung zur Markscheidekunst*, J. N. L. von Hanstadt, Pesth, 1835, p. 201.

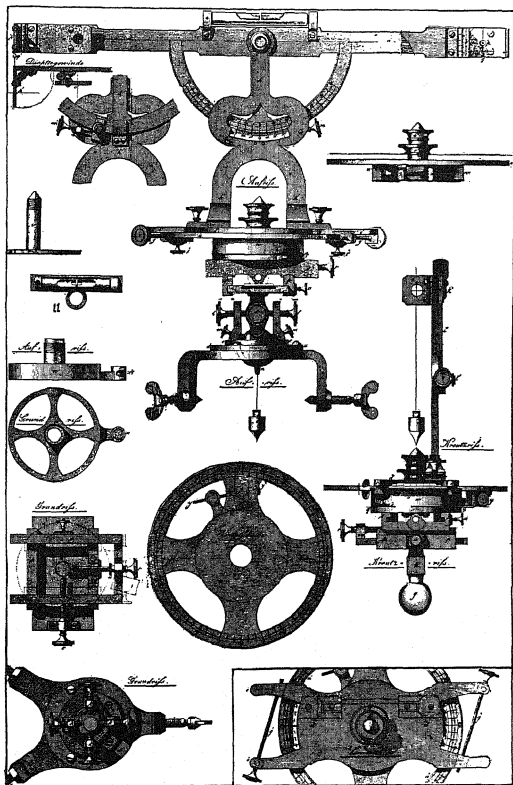
† Mentioned, and illustrated in one form, by Scott, *Trans.*, xxviii., 689.

terial, but because of its use in iron-mines. He says it consists of a rather large brass disk, graduated to degrees merely, and from left to right, like a plane-table compass. It turns at the middle about a ball-and-socket joint, both horizontally and in any vertical plane. There are two revolving arms, each with a hook at the end, to which are attached the measuring cords stretched to the fore and back stations. There are three hollow brass cylinders, one for each of these stations and one for the instrument-station, with iron screw-points below, to screw upon a plank or timber set across a mine-gangway* or upon a wooden plug. The three cylinders are of exactly equal height and large enough inside to receive the ball-and-socket joint under the disk. But when the instrument with this joint is set in the middle cylinder, the fore and back cylinders are filled each with a wooden plug having a projecting hook, to which the measuring cords are attached. Von Hanstadt says the apparatus is pretty clearly illustrated and described in Moehling's *Markscheidebuch* of 1793; but is not to be recommended for accurate surveys. 1 Because you do not dare to stretch the cord tight enough, since the screw-points of the cylinders easily break or bend. 2 At stations where the courses make a sharp angle, the ball-and-socket joint is under a strong pressure, that makes the turning of the disk difficult, and causes pretty strong friction upon the two brass arms, so that you cannot be sure the correct angle is indicated. 3. It is often difficult to set the instrument again precisely over a station for subsequent work, since the cross-plank cannot always be left in place. 4. The reckoning up of the courses of an extensive survey takes too much time and patience.

Von Hanstadt's Mine-Theodolite.—Von Hanstadt says he consequently devised another instrument that may fitly be called a mining-theodolite. This is, perhaps, sufficiently illustrated in Fig 108, compiled from his fragmentary drawings. The alidade with the sights is about 2 feet long. The brass plate *g*, before the instrument proper is set upon it, is first leveled with a movable spirit-level, *ll*, and bears the fixed spindle *v*, about which the upper part of the instrument revolves. This theodolite, rightly so called, has the telescope replaced by sights,

* See *Trans*, xxviii, 716, Fig 33

FIG. 108.

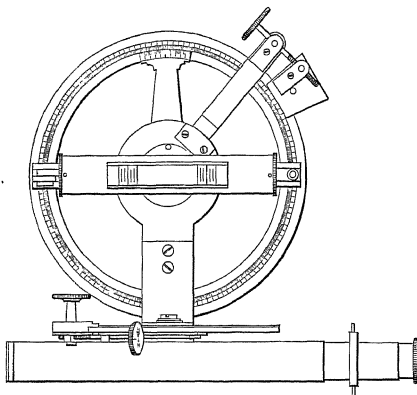


Von Hanstadt's Mine-Theodolite, Nearly $\frac{1}{8}$ Full Size.

with virtually a single central support for them; but has the semicircle attached below them, in the way peculiar to theodolites.

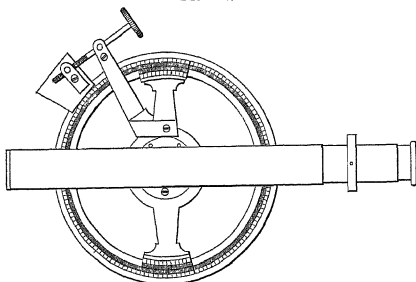
Combes's *Mine-Theodolite*.—The mine-theodolite of Prof.

FIG 109



Combes's Mine-Theodolite, Plan

FIG 110



Combes's Mine-Theodolite, Side View

Combes, of the Paris *École des Mines*, was described by him in 1836,* in an article giving full details of its construction and

* *Mémoire sur les levés de plans souterrains et description d'un nouvel instrument, propre à remplacer la boussole et le demi-cercle suspendus, par M Combes, professeur d'exploitation à l'École royale des mines (Annales des Mines, 3d series, vol 1x, 1836, pp. 81 and 217)*

examples of its use Figs. 109 and 110 will sufficiently explain it for the purpose of this notice. Fig. 109 is a plan of the instrument, as seen from above, and Fig. 110 a lateral view of the telescope and vertical circle.

Combes calls the instrument a mine-theodolite, and it is a theodolite in a common, wide sense of the word. But the telescope has the characteristic that distinguishes the transit from the theodolite; namely, the capacity of completely revolving in a vertical plane. The telescope, however, is supported on only one side, just as it is in the astronomical mural circle, first devised by Maskelyne and used at the Greenwich Observatory in 1811; and just as it had been in the *lunette murale*, and again in the yet older mural quadrant, first described (of course, with sights instead of the telescope) by Ptolemy about A. D. 150, and constructed, avowedly on his model, by Naṣir-eddin in Persia in 1260, but formerly supposed to have been invented by Tycho Brahe about 1581. Since the telescope supported on only one side tends by its weight and wear to sag downward, so as not to revolve in a truly vertical plane, it is now discountenanced, especially for observing, not a vertical angle, but the transit of a star across the meridian, and preference is given to the astronomical transit-telescope, which is supported on both sides, and has, moreover, an axle capable of reversion, end for end,—the invention of Roemer in 1700.

History of Solar Surveying Instruments.

BY J B DAVIS, CLEVELAND, OHIO

(Canadian Meeting, August, 1900)

THIS paper has been prepared at the suggestion of Mr. Dunbar D. Scott, to supplement his "Evolution of Mine-Surveying Instruments."[†]

Before entering into a detailed history of solar instruments, a few remarks will be made touching upon land-surveys in general, and on what has led to the development of these instruments.

* *Tycho Brahe*, by J L E Dreyer, Ph.D, Director of the Armagh Observatory; Edinburgh, 1890; p. 320

† *Trans*, xxviii, 679

IMPORTANCE OF SOLAR SURVEYING.

The True Meridian Needful—First of all, there is strong reason for the opinion that *all* land-surveys should be referred to the true meridian

Description by courses and distances is found in most deeds conveying real estate, and in records perpetuating the results of surveys. There are two noteworthy exceptions namely, in cities and villages, conveyances of land are often made by lot-numbers; and the United States government describes the land granted by its patents by reference to its general rectangular system of public land-surveys, without special rehearsal of the courses and distances bounding each grant. Outside of these exceptions, the description by courses and distances is perhaps the most simple and comprehensive available method; at all events, long custom has decreed its employment

Survey-lines are usually marked or monumented, but the marks are not always suitably clear and prominent, and duly recorded in the conveyance. Moreover, they may be lost or destroyed through carelessness and ignorance of their value; and, sooner or later, the lines must be retraced by a new survey—with what difficulty, when the original courses were taken by needle, only the surveyor knows. All that he can do is to turn for help to the facts of possession, or to adjacent surveys; or, if an original corner can be found as a starting-point, to satisfy himself, as to courses, with the limit of error in a needle-instrument, while, as to distances, he must determine, as nearly as may be, the difference in length between his steel tape and the worn and kinky Gunter's chain of the former survey. These perplexing problems we must continue to encounter until more accurate modern surveys shall have replaced the original ones.

The remarks apply also to the rectangular system of surveying United States lands, so far as the relocation of sub-divisional lines may be affected by the uncertainty of the indications of the magnetic needle.

But I wish to call particular attention to what may be termed an inconsistency in our modern land-surveys. Increased accuracy in them is demanded by the increase of land-values. Hence, measurements are more accurately made; a transit is used; and more care is taken in monumenting; so that the sur-

veys may be retraced with little difficulty, provided monuments enough are left for starting-points. At the same time, custom having prescribed the method of description, we still use courses, determined not by the needle, as originally, but by deducing the bearings from the transit-angles taken, and we use as a base the bearing of some one line, either measured in the field or copied from a deed. Right here comes in the inconsistency. we care nothing whether the bearing of the line we start from be a true one or not. We are well satisfied if it be only approximately true, we rely on the harmony of our survey, the fact that we have set monuments, have taken the angles with a transit, and have made our measurements carefully, and we assume that there can be no future difficulty in retracing the survey we have made. But the bearings of the lines in this modern and accurate survey, taken individually, mean absolutely nothing so far as the retracing of an accurate survey is concerned: only collectively are they of any value.

If we are to make an accurate survey, and are by custom forced to the use of bearings in our descriptions, why not have the bearings mean something, and be consistent with the rest of the survey? But that is not all. monuments are lost, and the cases are not infrequent when only one can be found, and then trouble begins, and care and good judgment are required in the solution of the problem. Evidently, the remedy is to refer the survey to the true meridian. This can be done by observing the north star, or an altitude of the sun, or by a solar instrument. Only by a reference to the true meridian can the "one stone problem" be at all times satisfactorily solved.

Old Methods of Meridian Determination.—The earliest instrumental methods of determining the true meridian in this country, as well as in Europe, were, first, by observing the polar star, taking into account its travel in an orbit the distance of which from the projected axis of the earth is known; secondly, by an altitude-observation of the sun and the subsequent calculation of the spherical triangle of which the sun, the zenith and the pole are at the vertices.

Surveyors do not take very kindly to observing the north star, and will resort to it only when absolutely necessary, because they object to the requisite night-work. The method of determining the azimuth by an altitude of the sun does not seem to

be popular, since it requires too much time for the calculation of the spherical triangle.

Davis's Solar Screen—It is appropriate here to mention the solar screen invented by Prof J B. Davis, of the University of Michigan, Ann Arbor, Mich, and perfected by the firm of Buff & Berger, Boston, Mass. It has been illustrated and described by Mr Scott,* Fig. 59. The invention does not belong in the same class as the mechanical solars to be described below; for it is not, strictly speaking, a solar attachment, but rather an appliance for more conveniently sighting the sun centrally in a direct solar observation. The use of the solar screen does not reduce the necessary computation, so far as the solving of the spherical triangle is concerned, for this work must still be done after the altitude of the sun is observed.

HISTORICAL SKETCH OF SOLAR SURVEYING-INSTRUMENTS.

As the theory and practice of solar work are now fully treated in all standard text-books on surveying, their full discussion is not deemed desirable here, and in what follows, a sufficient knowledge of astronomy in its application to solar work is presupposed.

Government Land-Surveys.—On May 7, 1784, the committee appointed by the Continental Congress, of which Thomas Jefferson was chairman, recommended that all public lands be divided into squares ten geographical miles on a side, and these sub-divided into lots of one square mile; but a subsequent amendment, made April 26, 1785, in which is recorded the first mention of "townships" and "sections," required that the main divisions should be only seven miles square, marked by lines running *due north and south*, and others crossing at right-angles. This ordinance, as still further amended, May 20, 1785, with a provision for townships containing thirty-six sections each, must be regarded as the actual beginning of our present government system of land-surveys; and General Rufus Putnam must be looked upon as its founder.†

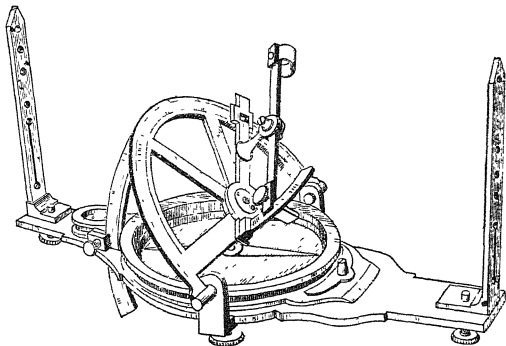
Burt's Solar Compass.—In 1833 Wm A. Burt, of Mt. Vernon, Mich., received an appointment as U. S. Deputy Surveyor, and

* *Trans*, xxviii, 743

† See the article by Col H C Moore in the *Jour Ass'n Engineering Societies*, vol 11, p 282

began work with an ordinary compass-instrument, as prescribed by the government. He found frequent occasion to reprove his chainmen, believing them to be guilty of gross inaccuracies. It turned out that the chainmen were correct enough in their work, and that the trouble was due to the treacheries of the magnetic needle. Mr. Burt satisfied himself that he could not sufficiently rely upon the accuracy of the indications of the needle; and he must also have concluded that the methods of determining the meridian by sighting Polaris or observing the sun's altitude were not practicable in the class of surveys upon which

FIG 111



Burt's Original Solar Attached to a Compass

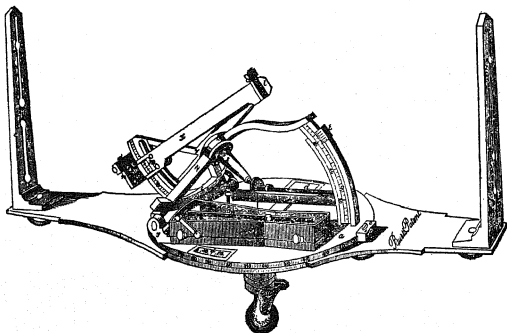
he was engaged. At all events, he began systematical work in developing a mechanical solar. By 1835 he was in Philadelphia, placing the model of his device in the hands of instrument-maker Wm J. Young; and in the same year his completed instrument received the Scott medal from the Franklin Institute. That instrument, shown in Fig. 111,* was designed to solve mechanically the celestial triangle, and consisted mainly of three arcs—the latitude-arc, the declination-arc, and the hour-circle.

Burt's solar compass did not attain perfection until about

* The figures of this paper are numbered consecutively with those of the Discussion of Mr Scott's paper, *ante*, p 783

1850. It then came into general use, and was for many years the standard instrument used in surveys of the United States public lands. He exhibited the perfected instrument (Fig. 112) at the London Exhibition of 1851; and Sir John Herschel then said: "I have long understood the elements of your instrument, but could not see how they would be carried out mechanically. It has fallen to your lot, Sir, not only to conceive the necessary astronomical elements, but also to carry them into practical effect mechanically." The same instrument was a part of the government exhibit at the Columbian Exposition in Chicago, and has now been added to the instrumental

FIG. 112.



Burt's Improved Solar.

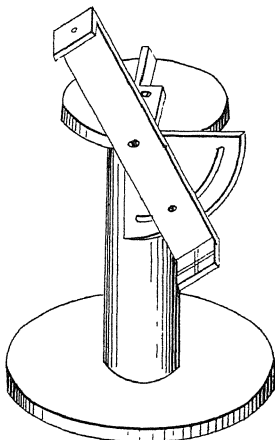
collection prepared for Paris. It is probably not too much to say that with Burt's solar, or some adaptation of it, fully 80 per cent. of the public lands of the United States have been laid out. The opinions of authorities on solar work in connection with government surveys would indicate that Prof. Baker's broad statement, quoted by Mr. Scott,* is without warrant and misleading.

Yeiser's Meridian Instrument.—In 1861 Frederic Yeiser, of Danville, Ky., introduced a meridian-instrument, Fig. 113, the operation of which was founded on the ancient method of

* *Trans.*, xxviii., 721.

bisecting the arc found by the observation of equal altitudes of the sun. Two parallel disks were connected by a vertical pillar. On the face of the upper plate revolved a sort of alidade beveled along one edge at one end, and carrying at the other end the lens-bar of the Burt solar. An observation was made at a certain hour in the morning, and the lens-bar was clamped to the vertical quadrant. In the afternoon, at a corresponding hour, the upper part of the instrument was moved about on the

FIG 113



Yeiser's Meridian Instrument.

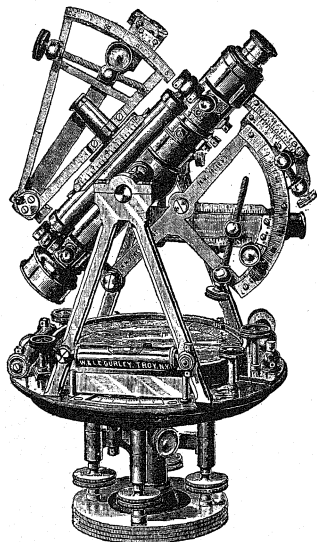
central pivot until the sun's image fell at the intersection of the "equatorial" and "hour" lines. Having drawn a pencil-line along the beveled edge of the alidade at each observation, the line that bisected the intervening space or arc was accepted as the meridian.

Schmoltz's Solar Transit—The next modification of the Burt solar has been referred to by Mr. Scott* as having been introduced in 1867, when the transit was coming into more general

* *Trans*, xxviii, 721

use, by Wm. Schmoltz, an instrument-maker of San Francisco. Since 1874 it has been mounted by Gurley, as in Schmoltz's model, upon the transverse axis of the transit-telescope, but with a means of adjusting the polar axis to movement in a truly vertical plane (see Fig. 38*). It is essentially the Burt declination-arc mounted upon its polar axis, which is now re-

FIG. 114.



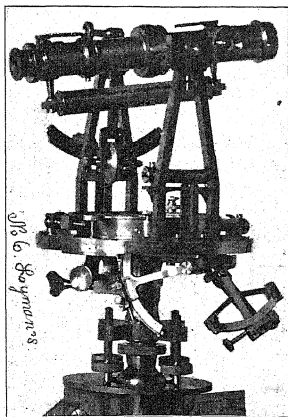
Schmoltz-Gurley Solar Transit, with Jones's Latitude-Arc.

versed from its position in Burt's compass, and may be secured to the telescope, or removed, by means of the thumb-screw at the top of the polar axis. It was customary to lay off the latitude on the transit's vertical circle or arc; but in the Schmoltz-Gurley model, reproduced in Fig. 114, the patent latitude-arc introduced by R. M. Jones in 1883 is used instead.

* *Trans.*, xxviii., 720.

This arc consists of an inner quadrant reading to minutes, and an outer segment reading to ten seconds of arc. The inner quadrant carries a reversible bubble-tube, which is adjusted for exact horizontality when the sun is in the meridian; and in all subsequent settings of the latitude the bubble is simply brought back to the center of its scale. This design of Schmoltz was one of the first, if not the very first, of the successful attempts to combine the solar attachment with the ordinary transit-instrument; though there had been a great deal of experiment-

FIG. 115.



Lyman's Solar Transit.

ing to improve on Burt's last model, in which a small telescope was mounted upon one of the sights, or set in Y-bearings across the top of both sights.

Lyman's Solar Transit.—In 1869 Benjamin S. Lyman, of Philadelphia, devised the solar apparatus shown in Fig. 115. Wm. J. Young & Co. (that is, Mr. Young and his partner, Charles S. Heller) had strongly advised him against placing the solar apparatus on the top of the telescope, and against using inclined standards for the telescope. The apparatus was, there-

fore, placed beneath the plates, for steadiness and protection against exposure; and was so designed that it could be used with a plane-table or other surveying instrument. The usual six-inch lens-bar was reduced in length to only two inches; but the proper focus and size of the sun's image was maintained by the total reflection of two rectangular prisms. Mr. Lyman filed a caveat of his invention in September, 1869, had the same description privately printed as specifications in December, 1870,* secured letters-patent in 1871, and the first instrument was made in 1872.

"It is true," says Mr. Lyman, "that, owing to the greater length of the lens-bar in Burt's compass, the latitude-arc has a decidedly longer radius and the declination-arc one slightly longer, but the radius of both arcs in the solar transit is two inches and a half, or the same as for the vertical and horizontal graduations of the transit proper, the size that is usually found convenient for reading to a single minute with a vernier "

When the vernier of the latitude arc reads 90° , the polar axis is truly vertical. The entire attachment weighs about a pound. In 1877 Young & Sons so constructed it that it could be attached and detached at pleasure.

Seibert's Solar Transit.—About 1869 (but it is not now possible to determine the exact year) F. R. Seibert, then with the U. S. Coast Survey, had Wm. J. Young & Co. make for him a transit with inclined standards, and place the solar apparatus directly over the compass, very much as in the original Burt instrument. The standards were inclined forward, so as not to cast a shadow, or otherwise interfere with the successful manipulation of the solar apparatus. It was to this instrument (Fig 116) that Mr. Scott assigned† the probable origin of the inclined-standard mine-transit; but from Mr. A. C. Young's contribution it appears that inclined standards were used as early as 1854 in Mr. Roberts's instrument.‡ Still, it is possible that the inclined standards made for him were inclined toward each other, forming a truss-support for the telescope.

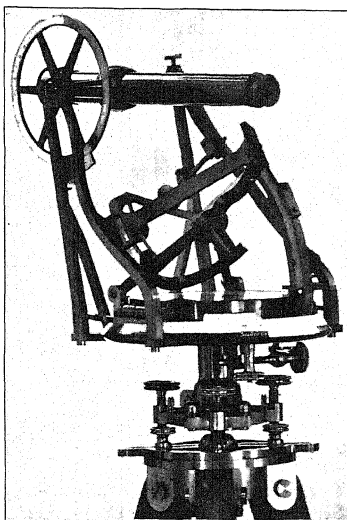
* *Specifications of Improvements in Solar Compasses* B. S. Lyman Bengal Printing Co., Calcutta, 1870. The specifications and caveat mention the former use of inclined standards, undoubtedly Seibert's plan, showing that it dates at least as far back as 1869.

† *Trans.*, xxviii, 725.

‡ *Ante*, p. 789.

Pearsons's Solar Attachment.—On July 27, 1875, Harrison C. Pearsons, of Ferrysburg, Mich., patented an attachment (Fig. 117), having the polar axis parallel to the optical axis of the telescope, and the hour-circle at right angles to it. As usual, the declination-plate revolved upon the polar axis; but the lens-bar was provided with a vernier as well as a lens and equatorial

FIG. 116.

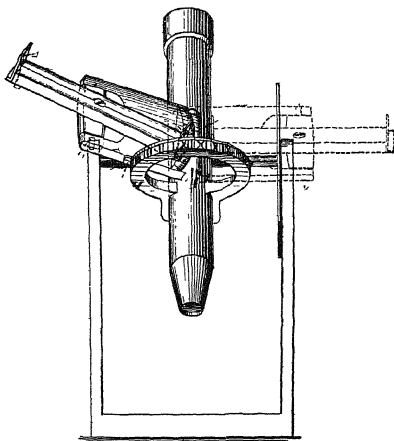


Seibert's Solar Transit.

lines at *each* end, and was mounted upon gimbals or a universal joint, whereby it could be brought at will to the surface of either broad face of the declination-plate. Also, the declination-plate was graduated on both its broad faces, so that it was possible to reverse the apparatus, in order to correct errors arising from unavoidable imperfection of construction and adjustment. It was the inventor's idea, as expressed in his letters-

patent, to utilize the telescope itself as the axis of the hour-arc, and this, to the best of my knowledge, is the first suggestion of letting the telescope of the transit-instrument become the polar axis. The manufacture of the attachment was first placed in the hands of the Gurleys, but the alliance between the manufacturers and the inventor was not a successful one.

FIG 117

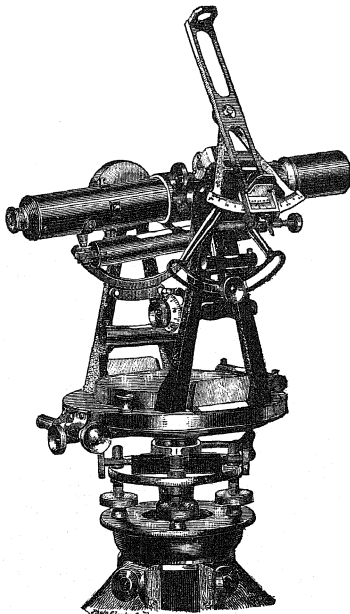


Pearsons's Original Attachment.

Buff & Berger's Pearson's Solar Attachment.—As first made by Buff & Berger, in 1878 (Fig. 118), the polar axis, while still parallel to the optical axis of the telescope, was placed over the bearings at one side, and was provided with a spirit-level on the "clamping-arc," to regulate it for true horizontality before elevation to the observer's latitude. This was especially desirable, as it was a part of the improvement to make it possible to attach or detach the whole apparatus as desired. After the latitude was set off, and the "clamping-arc" carrying the solar was clamped to the standard, the telescope was free to move in altitude without interfering with the position of the attach-

ment. The lens-bar was made single, instead of double, with a ground-glass focal plate, so that the sun's image could be observed from the rear with the ordinary reading-glass. But in 1879 Mr. Berger began substituting for it a small telescope of half-inch aperture and six-inch focus.

FIG. 118.



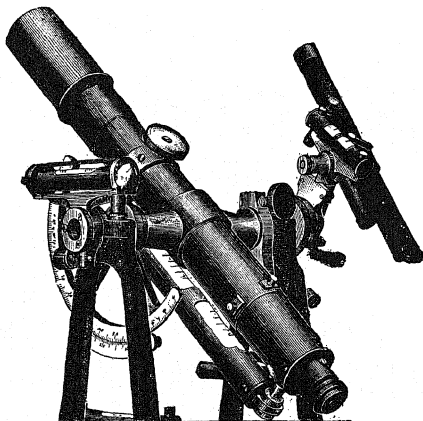
Buff & Berger's Pearsons Solar.

Buff & Berger's Solar Attachment.—In 1882 the Pearsons patents were assigned to Buff & Berger; and in 1885 the general design was changed so that the declination, as well as the latitude, could be laid off by the vertical circle. Fig. 119 shows this last-mentioned model. The attachment is fastened by a screw

to an extension of one end of the transverse axis of the telescope, and to the other end is clamped the latitude-level.

Holmes's Solar Theodolite.—In 1878 J. W. Holmes, instrument-maker in Batavia, N. Y., placed the telescope of a theodolite so as to work upon the declination-arc, or circle, in a very remarkable manner (Fig. 120). Between the standards, in the usual position of a telescope in an ordinary transit, he placed, in a plane at right angles to the vertical, a second circle, called the "dial-plate," graduated to read minutes. Within this ring re-

FIG. 119.

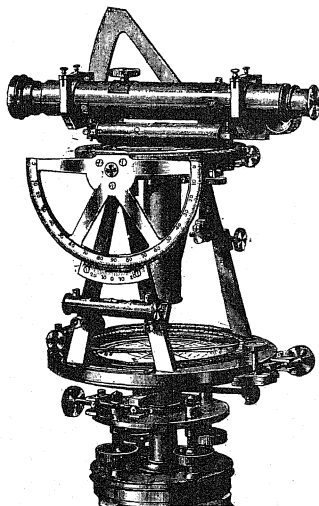


Buff & Berger's Solar Attachment.

volvéd, upon what might be termed the polar axis, a disk that, together with the "dial-plate," was also journaled at right-angles in the axis of the vertical arc. The disk carried the telescope on Y-bearings centered over the plates below; and upon the disk was fastened the declination-arc at one side of the telescope. The telescope was pivoted to the declination-arc by means of the Y-bearing nearest the ocular and could be moved in altitude at the objective end as required, and regulated to the nearest ten seconds of arc. Mr. Holmes's instructions for the use of the instrument are:

"Clamp the vertical arc to the latitude of the place, turning the dial-plate toward the north, if in north latitude. Move the telescope upon the declination-arc to the angular value of the sun's declination, corrected for time and refraction. But if the observation is made in south latitude, the telescope should be reversed in its Y's so that the object-glass shall be at the pivot of the declination-arc. Turn the upper part of the instrument upon the dial-plate, and the whole instrument upon its vertical axis, if need be, until the telescope can be centered upon the sun. Now the upper, or equatorial plates, are in a plane parallel to that of the equator; and when [ever] the telescope is [afterwards] brought back to the zero of the graduations, it is in the true meridian."

FIG. 120.



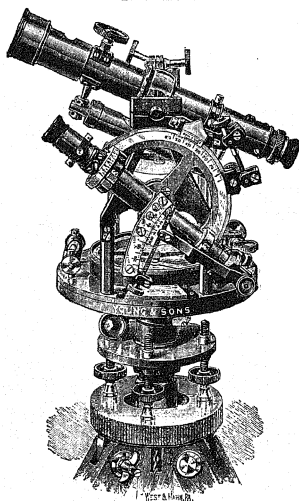
Holmes's Solar Theodolite.

The theodolite-type of the instrument made it necessary to counterbalance the eccentricity of the telescope and the other superimposed parts, by elongating the polar axis and considerably increasing its weight.

Smith's Solar Transit.—On September 14, 1880, Benjamin H. Smith, of Denver, Colo., made the telescopic polar axis a practical invention. To do this, however, he employed an entirely

separate telescope, to which are attached declination- and latitude-arcs, as shown in Fig. 121. To the side of a specially-designed standard is fixed a latitude-arc, in the form of a semi-circle, carrying two collars or bearings on its diameter, in which the solar telescope is free to rotate on its axis to any required position, as indicated by the hour-circle which circumscribes it. At the object-end of the telescope is a prism or reflector,

FIG. 121.



Smith's Solar Transit.

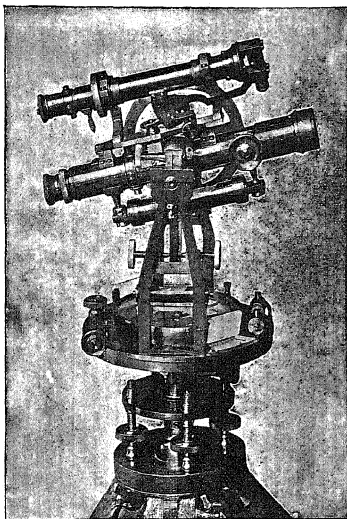
to which is attached an arm, at whose opposite end is a vernier that reads zero on the declination-arc when the plane of the reflector is at 45° to the optical axis of the telescope. Hence, if, after the proper latitude and declination are set off, the telescope is rotated on its own longitudinal axis, the reflected line of collimation will describe a celestial equator; and, both telescopes being in parallel planes, each will be in the plane of the meridian.

Since 1895, Mr. Young has mounted the solar telescope in

Y-bearings on the top of the main telescope, as shown in Fig. 122; and so has dispensed with the original design of the latitude-arc, in favor of the vertical circle.

Gardam's Solar Transit.—In the next year (1881), Joseph Gardam, of Brooklyn, N. Y., patented a device, in which the main telescope became the polar axis, upon principles very sim-

FIG. 122.



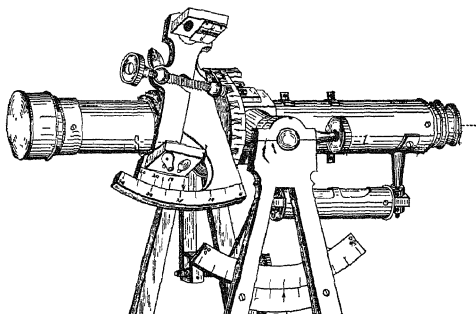
Smith's Improved Solar.

ilar to those suggested by Pearsons. As shown in Fig. 123, a flanged collar about the telescope is fixed and adjusted to the hub of the telescope by means of angle-pieces and capstan-head screws. A semi-annular ring, with its attached hour-circle and declination-arc, is placed over this collar, and held in any position by a set-screw that travels in a groove provided specially for it. In revolving on this collar-bearing about the telescope,

the declination-arc took up so much room that the length of the telescope-bubble was reduced to about half the ordinary length.

Saegmüller's Solar Transit.—In 1881 Geo N. Saegmüller, instrument-maker, in Washington, D. C., with the advice of certain government officials on the Coast Survey (with which department he was at one time connected), designed and patented a telescopic solar attachment, shown in Fig. 124, mounted upon an instrument of his own make. Mr. Scott has discussed the application of the enlarged attachment to mine-surveys,* but only the use of the smaller model in solar work will be touched

FIG. 123



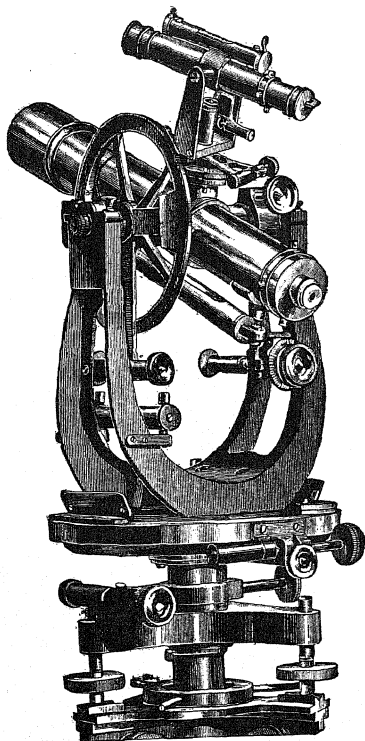
Gardam's Solar Transit

upon here. The attachment is fastened to the top of the main telescope upon a polar axis very similar in design to Schmoltz's modification of Burt, and is kept at right angles to the main telescope by means of capstan-head screws operating between the plates. The angular value of the declination, corrected for refraction and hourly change, is laid off on the vertical circle; the transit-telescope being depressed or elevated as the declination is north or south. The solar telescope, being previously adjusted to the same vertical plane with the main telescope, is then brought to a horizontal position, as indicated

* *Trans*, xxviii, 729.

by its own longitudinal bubble. This arrangement, as already noted, makes it possible to employ the vertical or latitude-circle

FIG. 124.

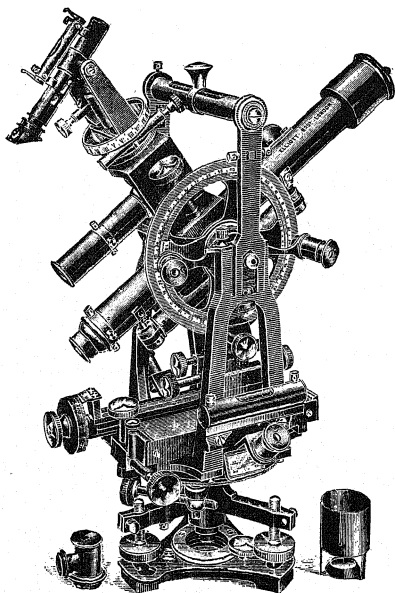


Saegmüller's Solar Transit.

as a declination-arc. The two telescopes will now form an angle equal to the declination, and the inclination of the solar telescope to its polar axis will be equal to the polar distance of

the sun. In this relative position, both telescopes are now so inclined that the vernier of the vertical circle indicates the co-latitude of the observer; and thus, on rotating the instrument upon its vertical axis until the sun's image is brought into the solar's field of view, the transit-telescope will be in the me-

FIG. 125.



Bell-Elliott-Eckhold Omnimeter, with Saegmuller's Solar.

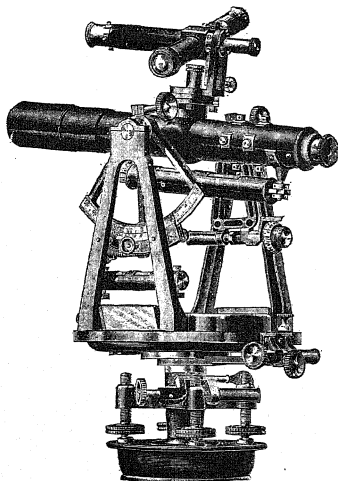
ridian. In recent years Elliott Brothers, of London, have been adding this attachment, provided with its own hour-circle, as shown in Fig. 125, to the Bell-Elliott improved Eckhold Omnimeter.

In 1887 F. E. Brandis' Sons, of Brooklyn, N. Y., introduced a modification of the Saegmuller solar (Fig. 126), in which the

small telescope is "broken" in the usual way, by placing a prism between the objective and ocular. For this device is claimed greater convenience in sighting the sun, as the eye-piece is always at the side of the instrument. The attachment is nicely balanced by placing the bubble opposite the objective-end of the broken telescope.

Walter Scott's Solar Attachment.—July 1, 1890, Walter Scott, of Hot Springs, Dak., patented an attachment of the Smith type,

FIG. 126.

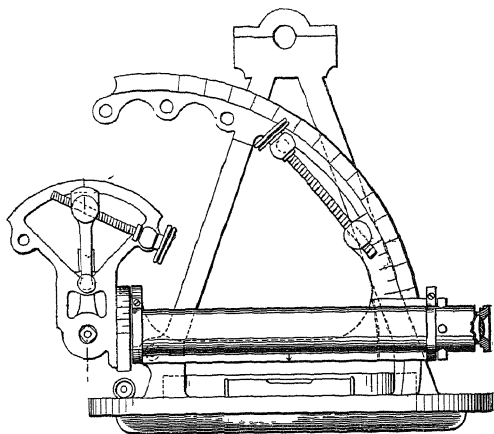


Brandis Solar Transit.

which he claimed could be readily attached to any ordinary transit-instrument. This, no doubt, is too great a claim. The sighting-tube having a single smoked lens in the ocular, and cross-hairs only at the objective-end, rested upon a base-plate pivoted to the lower end of one of the standards. The latitude-arc was permanently fixed to the same standard, and extended somewhat beyond at the upper end (Fig. 127), terminating in three extra perforations for the reception of the swivel-

block of the tangent screw. At the lower end of the vernier-arm of the declination-arc is a prism, or mirror-reflector, whose plane of reflection is at 45° to the axis of the sighting-tube, when the vernier of the declination-arc reads 0, and at the upper end of the vernier-arm there is a convex lens to converge the sun's rays upon the reflector. The vernier of the time-circle is a part of one of the collars which supports the sighting-tube. What has been said concerning the operations of the Smith solar will apply generally in this case. the main differ-

FIG 127



Walter Scott's Solar Attachment

ence in construction being the rigidity of the latitude-arc in the Scott attachment.

THE DAVIS SOLAR TRANSIT

History of Origin.—It having been claimed that solar instruments, or attachments for solving the spherical triangle mechanically, were not sufficiently accurate and certain in their indications to be used in transit-surveys, a committee was appointed, in 1894, by the Ohio Society of Surveyors and Civil Engineers, to test the accuracy of solar transits. The mem-

bers of this committee were Charles S. Howe, Professor of Mathematics and Astronomy, Case School of Applied Science, Cleveland, C. H. Burgess, a civil engineer of Cleveland, and the writer. Mr. Burgess being unable to give to the matter his personal attention, the investigations were made by Prof. Howe and myself. The committee succeeded in getting together solar instruments of all the prominent makers except one, so that ample opportunity was had for tests.

The report of the committee will be found in the annual volume of the Society for 1895. It states the conclusion that "errors of one minute, or even one and one-half minutes either way, are not infrequent, and any single observation would be uncertain to this extent." The observations referred to fall within an arc of three minutes. The committee also found it essential to have an accurately established meridian on which first to test the solars, since, when the sun was brought into its proper relation to the equatorial lines, the true meridian would not at all times be indicated. In order, therefore, to get close to the meridian, the instrument must first be set on an established meridian, and the actual relation of the sun's image to the equatorial lines must be determined. It was found that the sun's image would be sometimes above and sometimes below its proper central position. The further work had to be done in accordance with that determined position. We concluded that the difficulty arose from our inability to adjust the instrument exactly. From experience gained in these tests, the writer became satisfied that much of the objection of the profession to the mechanical solar is due to the fact that additional adjustments are required, that the adjustments are difficult to make, and that their maintenance is a matter of some uncertainty.

Believing that an instrument from which these difficulties are eliminated would be desirable, the writer began experiments to that end; and the first instrument, constructed by Ulmer & Hoff, Cleveland, O., was shown before the Ohio Society of Surveyors and Civil Engineers at their annual meeting at Dayton, O., in February, 1896. This transit-instrument had a vertical- or latitude-arc and a telescope capable of rotating in a sleeve about its longitudinal axis. The telescope had a fixed object-end, before which a mirror was so securely attached as to partake of any rotative motion of the telescope, yet capable

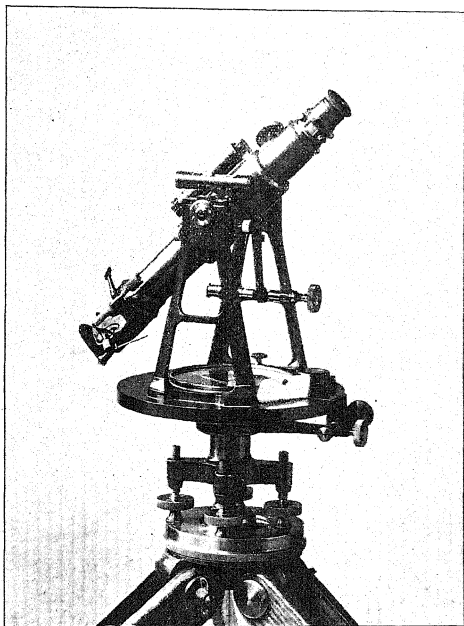
of revolving about an axis at right angles with the line of collimation. In 1898, the writer discovered that a small level placed upon the transverse axis of a telescope so constructed would enable the vertical- or latitude-arc to be eliminated. For, by setting off the latitude-angle on the horizontal limb, the mirror, reflecting a target, could be placed at the proper angle with the optical axis of the telescope, and then, by rotating the telescope through 90° , the same angle could be transferred to the vertical plane. As to measuring a vertical angle on the horizontal limb, it is not intended to do away with the vertical-arc in general practice, but only to replace the latitude- or vertical-arc in the J. B. Davis solar transit when the arc is only wanted for solar work. For practical reasons, this method of setting off a vertical angle is not applicable for latitudes much lower than 20° , but these are much lower than any within the boundaries of the United States. Articles describing the J. B. Davis solar transit have appeared in the *Journal of the Association of Engineering Societies*, November, 1896; *The Colliery Engineer*, July, 1897, *Engineering News*, April 28, 1898, and *Mines and Minerals*, April, 1899. It was patented January 21, 1897, and February 28, 1899.

Description —Figs. 128 and 129 represent the J. B. Davis solar transit, as made by Ulmer & Hoff, Cleveland, O, without vertical-, latitude- or declination-arc; all angles being measured upon the horizontal limb. Fig. 128 shows the solar transit with the reflector attached, and Fig. 129 with it detached. The solar transit is constructed with or without a vertical-arc, as may be desired. As the construction of a solar transit without a vertical-arc is a new departure, the method of operation without the arc will be described; the operation with a vertical-arc will then be obvious.

The transit-telescope is the polar axis in this instrument, and is so constructed inside a sleeve as to be capable of rotating on its longitudinal axis. Its object-end is fixed, and a reflector is securely attached to it. The usual vertical- or latitude-arc is dispensed with; but a level is placed upon the transverse axis of the telescope. The reflector is so constructed as to be capable of rotating with its frame about the line of collimation of the telescope as an axis, and also of revolving on an axis in its own plane at right angles to that

line; so that by sighting to a target the reflector may be placed in proper angular relation to the line of collimation in each meridian and latitude observation. This reflector-construction, together with the rotating transit-telescope, results in

FIG. 128.

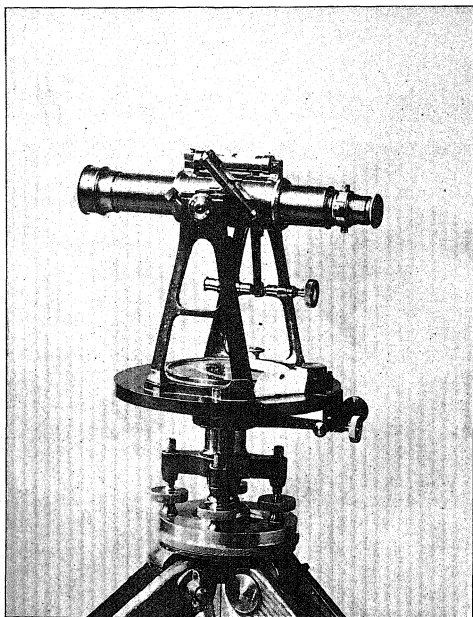


J. B. Davis Solar Transit, Reflector Attached.

doing away with the maintenance of all solar adjustments. Thereby, as the transit-telescope is used for solar work, not only is the accuracy of the instrument increased, but the certainty of its indications as well; because adjustments of special solar apparatus are difficult to make, are sensitive, and conse-

quently easily disturbed. All solar transits heretofore constructed require the maintenance of certain adjustments additional to those of the engineer's and surveyor's transit; and the majority have separate latitude- and declination-arcs. In

FIG. 129.



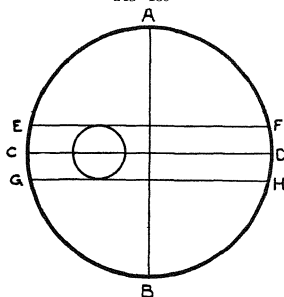
J. B. Davis Solar Transit, Reflector Detached.

this solar these arcs are dispensed with, and all angles are measured on the horizontal limb of the transit.

At the eye-piece end of the telescope is placed the cross-hair ring, or diaphragm, provided with the usual vertical and horizontal transit-hairs, AB and CD, and the two solar hairs EF

and GH, Fig 130. The small circle between the solar or equatorial hairs represents the sun in the field of view. Fig. 130 shows the diaphragm in its normal position for terrestrial work. The line of collimation can be adjusted on a fixed point by rotating the telescope in its sleeve, as an engineer's wye-level on its wyres. The solar hairs and rotating telescope are a convenience, even when only terrestrial work is required of the transit; for the solar hairs can be used for stadia-work, and the operator can, by rotating the telescope, quickly provide himself with a single hair for either transit- or level-work. At the eye-end of the telescope there is a shaded glass slide for

FIG 130



Transit and Solar Cross-Hairs

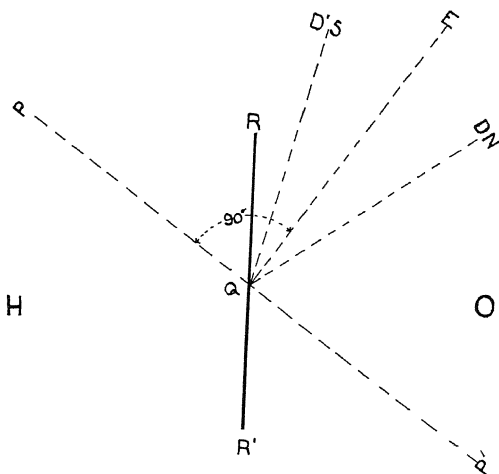
use in observing the sun. A diagonal prism is not required, as the eye-piece is elevated, in the position most favorable and convenient for the observer. The needle and the time-graduations on the telescope act jointly as a finder, to bring the image of the sun within the field of view. When the transit is not required for solar work, the reflector can be removed from the object-end of the telescope, and the telescope secured in its normal position by a set-screw. The central cross-hair is then vertical, and the telescope is firmly fixed in its sleeve.

The advantages obtained in this solar transit are (1) simplicity; (2) the use of but one telescope for solar and transit work; (3) the omission of the usual declination- and latitude-arcs, the graduated horizontal limb of the transit serving their

the exact latitude or declination is considerably multiplied in the azimuth. A want of knowledge on this point has led many into error, and some to doubt the efficacy of solar work entirely, under the wrong presumption that any hour of the day is equally favorable to such work.

Operation.—Fig 131 illustrates the target-sighting method of setting the reflector in its proper relation to the line of colli-

FIG 132



HO, A horizontal plane PP', Line of collimation of the transit RR', Reflector-plane EQ, Line from the point Q at right angles to the line of collimation QDN and QD'S, Declination-lines

mation for a meridian or latitude observation, and will be referred to, as the operation of the instrument is described in detail.

The optical axis of the telescope CC', the sighting-point, T¹ or T², and the image of the same in the reflector RR', are all in the same horizontal plane when the image of T¹ or T² is thrown into the line of collimation. When the reflector is placed at an angle of 45° to the line of collimation, the line of

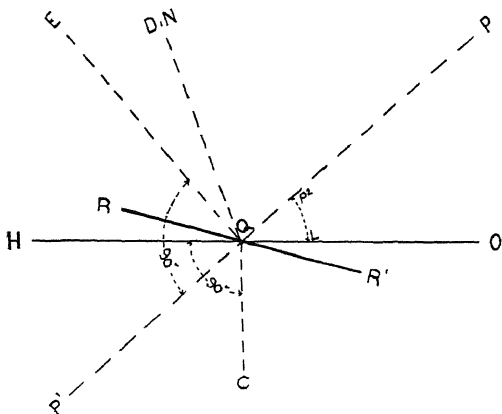
sight of the telescope is deflected 90° , and will represent the equator; and when the reflector is placed at an angle to the line of collimation of 45° plus or minus one-half the declination of the sun (according as the declination is north or south), the line of sight of the telescope will be deflected by an angle equal to the south polar distance of the sun. The target, as indicated in Fig. 131, has two sighting-points, T^1 and T^2 , T^1 alone is used in setting off the latitude, T^1 and T^2 are together used in setting the reflector in a meridian observation, as will hereafter be explained. The target T remains stationary and is set at right angles to a line drawn from the target-point T^1 to the transit-center, therefore, when the angle A is 90° , the distance $T^1 T^2 = C^2 R^c$. When the angle A becomes more or less than 90° , the distance $T^1 T^2$ must be reduced, so as to equal the perpendicular distance of R^c from the line $C^2 T^1$. To provide for this, the sighting-point T^2 is movable on the target, and an index-point and graduations enable the operator to set it in proper position for any angle A . The following statement will show the principles on which the operation of the solar is based.

Place the line of collimation of the transit-telescope PP^1 (Fig. 132) in the horizontal plane HO , and intersecting the reflecting-plane RR^1 at Q , with the reflecting-plane so placed (at 45°) that any point E situated in the horizontal plane and in a line at right angles to the line of collimation from the point Q will be reflected along the line of collimation; or, again, in such other position that reflection in the line of collimation will take place from any point, such as $D^1 N$ and $D^1 S$, lying in the horizontal plane and situated either to the right or left of the point E and in the line from the point Q that makes an angle with the line EQ equal to the declination of the sun at the time. The reflecting-plane will now be perpendicular to the horizontal plane, in which the line of collimation lies; and the horizontal angle between the line of collimation and the intersection of the two planes will be such as the declination of the sun at the time of observation may require.

If, then, keeping this angle unchanged, the line of collimation PP^1 be inclined, as in Fig. 133, to the horizontal plane HO , at an angle equal to the latitude of the place, $P^2 L$ (in the manner to be presently described), and the reflector-plane be

rotated about that line as an axis, the sun can be followed in its passage from east to west, in case the line of collimation is in the plane of the meridian. The line of collimation may be brought into that plane by a horizontal circular motion about QC, the vertical axis of the instrument, at right angles to the horizontal plane. At the same time the line of collimation, and with it the reflecting-plane, is rotated about itself as an axis, until the center of the image of the sun is seen exactly in the line of collimation. The line of collimation will then be in the meridian plane of the observer.

FIG 133



Again, returning to Fig. 131, let it be understood that in the operation of this instrument the optical axis of the telescope, or the line of collimation, is what is termed the polar axis in other solar instruments, so that any line perpendicular to the optical axis from a point in the reflector-plane at its intersection with the optical axis of the telescope produced will be in the plane of the equator. The sun in its position, on one or the other side of the equator, in its varied positions of declination throughout the year, will be represented by the correspondingly varied horizontal-angular position of the target as sighted

to in each observation. This varied position of the target with reference to the aforesaid equatorial line is determined by the angle A , which varies with the sun's declination. It will thus be seen that the target is made to bear the same relation to the optical axis of the telescope, and the aforesaid line perpendicular thereto, as the sun bears to the polar axis and equatorial line at the time of observation; and that if the telescope be dipped, with reference to a horizontal plane, sufficient to conform to the position of the earth's axis at the point of observation, *the sun's image can only be seen in the optical axis of the telescope when the telescope has been brought into the plane of the meridian.*

To Set the Telescope to the Latitude-Position —1. See that the usual transit adjustments are carefully made. Loosen the set-screw which passes through an arm of the telescope-axis and engages the telescope, so that the telescope can be rotated in its sleeve until the solar lines have become vertical. When the rotation has been made, secure the telescope by the same set-screw. Clamp the solar reflector-frame to the object-end of the telescope, placing it so that the reflector will be approximately in a vertical plane and parallel to the line of collimation, so as not to obstruct the view through the telescope. Place the transit-center vertical by means of the plate-levels and the telescope-level; and then, while the telescope is level, sight a target (at any convenient distance, 20 to 200 feet from the transit) with the stationary sighting-point T^1 on both the central vertical and the horizontal cross-hairs, and the movable sighting-point T^2 on the horizontal cross-hair only. (See Fig. 131.)

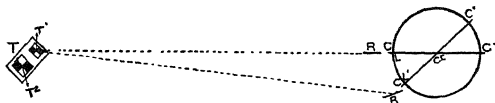
2. Observe the reading of the horizontal limb, and then set off on that limb an angle equal to the latitude of the place of observation; and, with the telescope still horizontal, by rotating the reflector about its own, then vertical, axis, bring the image of the target-point T^1 into the line of collimation of the telescope. (See Fig. 134.)

3. Without changing the angle made by the reflector with the line of collimation, return to the first reading of the limb; the telescope will then again be directed to the target-point T^1 . Loosen the set-screw before referred to, and rotate the telescope 90° , securing it by the set-screw in this position. Dip the telescope until the reflected image of the target-point T^1 appears

in the line of collimation, and then bring the bubble of the transverse-axis level to a central position. (See Fig. 135) The telescope is now dipped to the required latitude-angle, and the axis-level enables the operator at any time to restore the telescope quickly and accurately to the proper latitude-position

To Determine the Meridian.—1. Again place the solar hairs

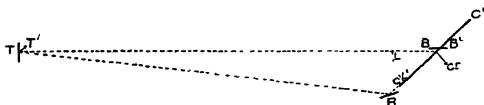
FIG 134



Showing the Latitude-Angle in a Horizontal Plane T, Target T', Stationary sighting-point T', Movable sighting-point C C', Transit-telescope in two horizontal positions C', Center of horizontal revolution of the transit telescope R, Reflector L L', Latitude angle T', C' and the image of T' in R are in a horizontal plane.

perpendicular, remembering that the transit-telescope will be directed to the target-point T', when the transit-limb is made to indicate the first angle read in the operation of dipping the telescope to the latitude position. Now, set off an angle equal to 90° , plus or minus the corrected declination of the sun at the time of observation, according as the sun is north or south

FIG 135



Showing the Latitude-Angle in a Vertical Plane T, Target T', Stationary sighting-point C C', Transit-telescope C', Center of revolution of the transit-telescope R, Reflector L L', Latitude angle B B', Transverse-axis level T', C' and the image of T' in R are in a vertical plane

of the equator. This angle is the south polar distance of the sun, and is indicated as angle A in Fig. 131. With the telescope level, place the reflector in such a position that the image of the target-point T' will appear exactly in the line of collimation of the telescope. (The target-point T' is sighted to, for the purpose of allowing for the parallax due to the reflector's being at the object-end of the telescope, and not at the transit-center ;

and the distance $T^1 T^2$ is controlled by the angle A , as before explained.) By this operation, the plane of the reflector is made vertical, and at the same time its intersection with the horizontal plane of the collimation of the telescope will be at such a horizontal angle with the collimation as the declination of the sun at the time of observation requires (See Fig. 131.)

2. Having now placed the reflector in proper angular relation to the line of collimation, turn the object-end of the telescope south, dip it from a horizontal position by an angle equal to the latitude of the place of observation, by means of the transverse-axis level (previously set to indicate the proper latitude); and securely clamp the telescope. Loosen the set-screw, so that the telescope rotates in its sleeve. It will be seen that the sun can then be followed in its daily motion. Rotate the telescope in its sleeve, and at the same time turn the whole instrument horizontally, until the sun appears exactly between the solar hairs, and the perpendicular hair approximately bisects it. Then firmly clamp the transit-center. *The telescope will then be in the true meridian.*

3. Bring the telescope back to its normal position in its sleeve, and secure it by the set-screw. Unclamp the telescope-axis and fix the meridian-line by suitable points. In doing this the reflector is unclamped and placed parallel to the line of collimation. In this position it forms no obstruction whatever to the line of sight.

To Determine the Latitude.—1. Place the reflector in proper angular relation to the line of collimation (as in the instructions for determining the meridian), so as to reflect into that line the sun's image when at noon-declination. Rotate the telescope 90° in its sleeve, and secure it by the set-screw.

2. Dip the telescope, and follow the sun until it has attained its greatest altitude. Then set the latitude- or transverse axis level in a horizontal position, in order that the telescope may be returned to the proper latitude-position whenever desired.

3. To read the latitude-angle from the transit-limb, first place the telescope in the vertical plane passing through the target-point T^1 , by returning to the same reading of the limb as indicated when the target was first sighted, in the operation of setting the reflector to its declination-position. Still retaining the telescope in its established latitude-position, change the

reflector so as to throw the image of the target-point T^1 into the line of collimation. Now place the telescope in a horizontal plane, rotating it 90° ; and then move it horizontally until the target-center is again seen reflected in the line of collimation (See Figs. 134 and 135.) Then read off the latitude from the transit-limb.

The Properties of Brass Made from Copper Containing Sub-Oxide, with Observations of the Effect of Oxygen on Copper

BY ERWIN S. SPERRY, BRIDGEPORT, CONN.

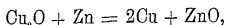
(Canadian Meeting, August, 1900)

I. INTRODUCTION

THE oxidation of metals melted in contact with air takes place with dissimilar results. Tin, lead or zinc are examples of a class, the oxides of which float on the surface of the melted metal. First a film is produced, which covers the surface; then, if agitation from any cause exposes new metal to the action of the air, additional oxidation takes place, and the film is increased in volume. This change goes on until a considerable quantity of oxide (or "dross," as it is technically called) is formed; depending, of course, upon the duration of the exposure of the metal to the atmosphere. When such metals are poured, the dross may be skimmed off; and clean metal will be left underneath. The removal of such oxides is, therefore, merely a mechanical process. In the case of copper, however, the result is quite different. The sub-oxide of copper (Cu_2O) is readily soluble in molten copper, and therefore, instead of the formation of a film of oxide, to be finally removed as dross, the surface of the metal remains bright and clear, because the oxide has been dissolved as soon as it was produced.

It is customary in the process of copper-refining to leave a small quantity of oxide in the metal, in order to oxidize any traces of bismuth, arsenic or antimony which have not been entirely removed. As a result, these metals exist in the commercial product as oxides, and not as metals, which would form an

alloy with the copper and so injure its quality. In making copper bars for the manufacture of wire of high electrical conductivity, and cakes to be rolled into sheet, this practice is, without doubt, beneficial, but it does not improve the copper for the manufacture of brass or other alloys. Zinc is a strong reducing agent; and the study of its thermo-chemical reactions has shown that it will reduce not only the oxide of copper according to the reaction



but the oxides of bismuth, arsenic and antimony as well. In the manufacture of brass, therefore, all the other metallic oxides are reduced to metal, with the formation of oxide of zinc.

It is well known that, by reason of the absorption of oxygen, copper rapidly deteriorates when melted in a crucible. Each successive melting, therefore, injures its quality. Small amounts of oxygen do not seem to affect appreciably the "hot-working" qualities of copper, but tend to make the metal cold-short. In the manufacture of sheet-copper the tendency to crack during the process of rolling is overcome by reason of the fact that the metal is "broken-down" hot; the cold-working which is afterward put upon it does not then have the tendency to crack it. Pure copper is much softer than that which contains oxygen.

In order to determine the influence of sub-oxide of copper on brass, it was necessary to make copper containing varying quantities of sub-oxide, and then to use these products instead of the pure material. The description of such experiments, given below, includes also observations on the effect of the sub-oxide on the properties of copper.

It was decided to introduce into the copper the maximum amount of sub-oxide, and to use this product, first without any admixture of pure material, and then with the addition of varying amounts of pure copper, thereby decreasing the percentage of contained oxygen. The ideal method, however, seemed to be to melt pure copper in a crucible, and then add some oxidizing agent like saltpeter. Such a method was also tried; and, while the results were not satisfactory, they may be of interest.

II THE PROPERTIES OF COPPER CONTAINING SUBOXIDE FORMED BY FUSION WITH SALTPETER.

Experiment No. 1.—Twelve lbs of Lake copper were melted in a new plumbago crucible, without any charcoal or flux, and, when the temperature had reached the proper degree, 4 oz. of saltpeter were added, in small portions at a time. Effervescence followed the contact of the copper with the saltpeter, and the latter then fused to a liquid slag which, as soon as it reached the side of the crucible, became incandescent, apparently by reason of the reaction between the plumbago and the saltpeter. The copper was then immediately poured into ingots. The melted metal ran quite freely, without any film of oxide, and set quietly with a level top. The ingots fractured easily, and lacked the usual toughness of pure copper, although they could be bent to a considerable extent before breaking. The grain of the fracture was fine, free from crystallization, and would be called, in the copper industry, “dry.” The ingots could not be rolled cold, but worked hot nearly as well as pure copper, although the ingot was of such size* that it did not admit of accurate comparison with commercial work. Duplicate analyses of the product gave the following results:

	A	B
	Per cent	Per cent
Copper,	99.77	99.78
Oxygen (by difference),†	23	22
	<hr/> 100.00	<hr/> 100.00

As the amount of oxygen introduced into the copper in this treatment was not sufficient for the purpose of this investigation, another test was made.

Experiment No. 2.—Ten lbs of Lake copper were melted in the same manner as before, and half a pound instead of 4 oz. of saltpeter was added. The action in the two instances was identical. When the metal was poured out into ingots it ran

* The size of the ingots was 1 in. by 2 in. by 12 in.

† Inasmuch as the author lacked proper facilities for making accurate oxygen determinations, a sharp copper-determination was made, and the oxygen was then determined by difference. For these particular determinations, as the amount of oxygen was large, it is believed that such a method was sufficiently accurate. The quantity of the other elements in the copper is so small that the results are not appreciably affected thereby.

freely, and the top remained level. The ingots broke easily, and the fracture was "dry." The copper worked hot, but could not be rolled cold. The results of the analyses were

	A	B
	Per cent	Per cent
Copper,	99 90	99 91
Oxygen (by difference),	10	09
	<hr/> 100 00	<hr/> 100 00

Such results are almost paradoxical. Although the quantity of the oxidizing agent introduced was double that of the previous experiment, the amount of oxygen remaining in the copper was only half as great. The experiment was therefore repeated.

Experiment No. 3.—Thirteen lbs. of Lake copper were melted as before, and 12 oz. of saltpeter were added. Of the resulting copper no analysis was made, but it was identical in fracture and other physical qualities with that of Experiment No. 2.

In carrying out the last two experiments even greater care was used than in the first. The mixture was stirred thoroughly after each addition of saltpeter, and the crucible was allowed to remain in the fire for some time. The results were not what was anticipated; and the apparent paradox may, perhaps, be explained by the assumption that the saltpeter first acts as an oxidizing agent, but that, after the available oxygen has all been given off, the potassium nitrite (or perhaps carbonate, formed by the reaction between the plumbago and the saltpeter) acts as a reducing agent. These experiments, however, are too meager to establish firmly such a theory; and, as further investigation in that direction would be beyond the scope of the inquiry recorded in this paper, the additional experiments leading up to the production of copper containing a large amount of oxygen were conducted along other lines

III. THE PROPERTIES OF COPPER CONTAINING SUBOXIDE FORMED BY ATMOSPHERIC OXIDATION OF THE MOLTEN METAL.

Experiment No. 4.—Twelve lbs. and 14 oz. of Lake copper were melted in a new plumbago crucible without charcoal or flux of any kind. When the metal had melted and reached a bright red heat, the cover of the furnace was removed, and air

was allowed to play over the surface until the whole mass became solid. Heat was again applied, and the oxidizing operation was repeated. The copper was thus exposed to the action of the air for about three hours. During the last operation, it was not allowed to become solid, but was poured directly into the ingot-moulds. The metal was covered with a slight film, and ran very thick and pasty, bubbling violently in the crucible while being poured; portions even were projected a considerable distance while the ingots were setting. In this instance, unlike that of the copper produced by the action of saltpeter, the tops of the ingots swelled enormously through the evolution of gas. The ingots broke easily, and the fracture was darker in color than pure copper, in fact it resembled that of red brick more than of any other material. The metal was filled with blow-holes, many of which were quite large. The chips were very short; and, when drilled, the metal behaved like cast-iron; the usual toughness, experienced when copper is worked, was entirely absent. Naturally the metal could not be worked cold; but if heated to a bright red heat, it would forge to a thin edge, with only a few edge cracks. A proper temperature was necessary, however, to obtain these results. When bent over on itself, even at any temperature, it fractured at the bend. An analysis gave the following results.

	A	B
	Per cent	Per cent
Copper,	98 48	98 58
Oxygen (by difference),	1 52	1 42
	<hr/> 100 00	<hr/> 100 00

Experiment No. 5.—Fifteen lbs. of Lake copper were melted as before. The furnace-cover was then removed, and air was allowed to come into contact with the metal for half an hour, after which the copper was poured into ingots. The mass behaved exactly like that of the previous experiment. In the ingot, the only difference noted was the absence of the extreme brittleness manifested in the product of Experiment No. 4. The ingots would bend slightly before breaking. The results of analysis were

	A	B
	Per cent	Per cent
Copper,	98 88	98 79
Oxygen (by difference),	1 12	1 21
	<hr/> 100 00	<hr/> 100 00

Experiment No 6—Twenty lbs of Lake copper were melted as before, and the oxidizing operation was repeated. The metal was exposed to the action of the air for about half an hour, and was then poured into ingots. Contrary to expectations, and although an analysis gave nearly the same amount of contained oxygen as in the material produced in Experiment No 5, the surface of the ingots did not swell, but shrunk slightly. The results of the analysis were

	Per cent
Copper,	98.78
Oxygen (by difference),	1.22
	<hr/> 100.00

The fracture of this material, while "short," was practically free from blow-holes. One of the ingots was forged hot from a thickness of 2 in. to $\frac{1}{2}$ in. It forged much harder than pure copper, and cracked at the edges. An attempt was made to roll it cold at this thickness; but, when a slight punch was taken, it cracked to pieces. Another ingot was then forged down hot to $\frac{1}{4}$ in. diameter, and a second attempt was made to reduce it cold. It was rolled with great difficulty to a thickness of 0.025 in. In order to prevent the sheet from cracking to pieces, it was imperative that no bending should take place. It readily yielded to compression; but any transverse strain invariably resulted in fracture.

IV. THE PROPERTIES OF COPPER FREE FROM OXYGEN.

Experiment No. 7.—Twenty lbs of Lake copper were melted under a good layer of charcoal, and, when at a proper heat, poured into a closed mould, $\frac{5}{8}$ by $2\frac{3}{8}$ by 24 in. in internal size, and oiled with lard-oil. During the melting every precaution was taken to keep the metal well covered with charcoal, and not to allow it to remain in the fire after the normal temperature for pouring had been reached. The plate produced had every appearance of a sound casting. It was free from spills or cold shots, and the top remained perfectly level while cooling. It was rolled cold from 0.602 in. to 0.500 in. thickness; and many large cracks started from the edges. When the reduction had reached 0.387 in. the plate had cracked to pieces. The metal worked hot, however, fully as well as copper which had not been remelted.

The preceding experiments demonstrate that oxygen renders copper particularly sensitive to cold-working, but, unless present in excessive amount, does not materially affect its hot-working properties.

A peculiarity of copper containing oxygen, and one which, it is believed, has been appreciated for some time past, by heaters coming into occasional contact with such material, is its sensitiveness to variations in the heating-temperature. The more oxygen copper contains, the higher the rolling-temperature must be

V THE PROPERTIES OF BRASS MADE FROM COPPER CONTAINING OXYGEN.

In the following experiments, made to determine the influence of copper containing oxygen on brass, the material resulting from the preceding experiments was used. In order to reduce the percentage of contained oxygen, varying amounts of pure copper were added, as occasion demanded. The base-composition contained 60 per cent. of copper and 40 of zinc.

Experiment No 8 — Brass from Copper Containing 1.47 Per Cent. Oxygen — Of the copper from Experiment No 4, 6 lbs. were melted without charcoal or flux, and, at a temperature sufficient for brass-making, 4 lbs. of Bertha zinc were added, in small portions at a time. As each portion of zinc was added, the mass "flared" and "sputtered" enormously, many times more violently than at the corresponding stage in brass-making—in fact, with almost explosive force. Large clouds of zinc oxide were given off, and the result seemed quite similar to the condition which would exist were the copper at a white heat. After the second portion of zinc was added the mass began to thicken, and became difficult to stir.

When all the zinc had been added, the brass had become solid and could not be stirred at all. On the supposition that the mass had perhaps become solid on account of a fall in temperature, the furnace-cover was put on, and the crucible was again heated for some time. A violent heat for fifteen minutes did not suffice to liquefy the mass and, therefore, it was poured into ingots. Although it smoked violently when removed from the fire, only a small portion ran out, the rest remained in the crucible as a solid mass. The metal which ran out had every

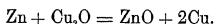
appearance of pure brass; it flowed freely into the mould, and seemed to be thoroughly alloyed. An analysis of this portion showed:

Copper,		Per cent
Zinc,		82.97
		17.11
		<hr/> 100.08

The ingot was rolled cold from a thickness of 0.518 in. to 0.089 in. without annealing; and, though it cracked considerably on the edges, rolled much better than would be expected from such material.

The mass left in the crucible, while apparently infusible, had every appearance of a thoroughly alloyed composition. It had the color and luster of brass; and, except by reason of its shape, one would scarcely believe it to be anything but a pure alloy. Its form, however, revealed its infusible nature; as it resembled rather a conglomeration of nodules than a mass of melted metal. Inasmuch as subsequent experiments demonstrated its infusible nature, and in view of the fact that its formation takes place if the amount of oxygen in copper is excessive, the author has applied the name of "*Brass Salamander*" to it. A reproduction from a photograph of the salamander obtained from Experiment No. 8 is shown in Fig. 1. The reactions which result in the formation of the salamander may be stated as follows:

The sub-oxide in the copper is reduced to metal by the zinc, with the formation of zinc oxide, according to the reaction

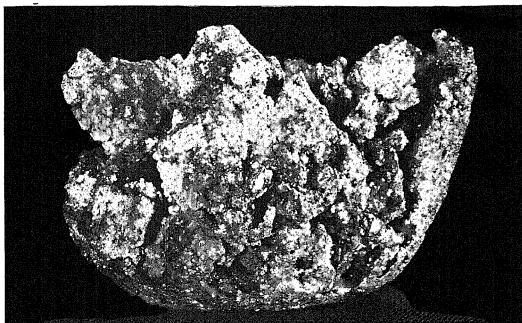


The heat generated by the reaction produces enormous "flaring" and large loss of zinc. The zinc oxide having been formed by the reduction of copper oxide is distributed through the metal in the same manner that a precipitate is formed by a chemical reaction; and, inasmuch as it is a particularly refractory substance, the alloy is rendered infusible, with the consequent formation of the "salamander."

The weight of this salamander was 5 lbs. 10 oz.; and that of the metal poured into ingots 2 lbs. 6 oz.

Experiment No. 9.—Brass from Copper Containing 1.17 Per Cent. Oxygen.—In carrying out this experiment, the same weights and methods were used as in Experiment No. 6, except that instead of using copper containing 1.47 per cent. of oxygen, that which resulted from Experiment No. 5 (containing 1.17 per cent. oxygen) was used. The same reaction occurred when the zinc was added; a salamander was left in the bottom of the crucible; and in all other respects the result was the same as that of the preceding experiment. The metal which ran out was rolled without annealing from 0.510 in. to

FIG. 1.



Brass Salamander.

0.089 in. in thickness. It behaved in the rolling-process like the sheet previously rolled, *i.e.*, it cracked much more on the edges than pure brass of the same composition. An analysis showed:

	Per cent.
Copper,	83.90
Zinc,	16.10
	<hr/> 100.00

Weight of salamander, 4 lbs. 14 oz.; weight of metal poured into ingots, 2 lbs. 3 oz.

Experiment No. 10.—Brass from Copper Containing 0.58 Per Cent. Oxygen.—In this experiment there were melted together 3

lbs. of pure Lake copper and 3 lbs. of copper containing 1.17 per cent of oxygen. No flux or charcoal was used. When the proper temperature had been reached, 4 lbs. of Bertha zinc were added in small portions at a time. The same violent action occurred as in the previous experiments, and the mass thickened and became solid. More zinc was added, however, before the solidification took place, than could be introduced into copper containing a greater percentage of oxygen.

When all the zinc had been introduced, the alloy was poured into ingots. The crucible smoked freely when removed from the fire, but, as usual, only a portion of the mass would run out. That which was liquid ran as freely as pure brass. The usual salamander remained in the crucible, but was much smaller than those previously obtained. An analysis of the portion poured into ingots showed

	Per cent
Copper,	64.68
Zinc,	35.56
	<hr/> 100.24

Experiment No. 11.—Brass from Copper Containing 0.39 Per Cent. Oxygen—Melted 4 lbs. of Lake copper together with 2 lbs. of the copper containing 1.17 per cent of oxygen. When the heat was right, 4 lbs. of Bertha zinc were added, in small portions at a time. The reaction was much less violent than in any of the preceding experiments, and the salamander was somewhat smaller. The portion which ran out of the crucible was filled with small red specks and nodules, apparently of un-reduced sub-oxide of copper. Analysis of the liquid portion showed

	Per cent
Copper,	64.58
Zinc,	35.48
	<hr/> 100.06

The weight of the salamander was 1 lb. 12 oz., and that of the metal poured into ingots, 7 lbs. 5 oz.

Experiment No. 12.—Brass from Copper Containing 0.24 Per Cent. of Oxygen—Melted 5 lbs. of pure Lake copper and 1 lb. of copper containing 1.4 per cent. of oxygen, without charcoal or flux, and then added 4 lbs. of Bertha zinc. The latter metal was

added in two portions, and the mixture was carefully stirred after each addition. The reaction which followed was only a trifle more violent than would have taken place had the copper been entirely free from oxygen. No salamander was left in the crucible. The metal was poured into a mould $\frac{5}{8}$ by $2\frac{3}{8}$ by 24 in. in internal dimensions. The surface of the mould was oiled with lard-oil. The alloy ran as freely as brass made from new copper, and the superficial appearance of the plate was fair.

The plate was rolled from 0.590 in. to 0.440 in. thickness, without annealing; and no cracks appeared. Annealed and rolled to 0.297 in., it cracked slightly on the edges. Annealed and rolled to 0.133 in., it showed many edge-cracks. Annealed and rolled to 0.059 in., it showed no additional edge-cracks. Analysis showed

Copper,	.	Per cent
Zinc,	.	60.44
		39.65
		<hr/> 100.09

*Experiment No. 13.—Brass from Copper Containing 0.55 Per Cent. Oxygen, but Treated Differently from Experiment No. 10—*Melted $3\frac{3}{4}$ lbs. of Lake copper and $2\frac{1}{2}$ lbs. of copper containing 1.47 per cent of oxygen, but instead of allowing them to melt without flux or charcoal, as was done in experiment No. 10, plenty of charcoal was used, both before and after the metal had begun to melt. When the suitable temperature had arrived, 4 lbs. of Bertha zinc were added in small portions at a time, and the mixture was thoroughly stirred after each addition. There was considerable action when the zinc was added; but much less than that which took place in Experiment No. 10. No salamander was formed. Poured directly into a mould of the dimensions given in the previous experiment. The mould was oiled with lard-oil, and care was taken to surround the stream of liquid with gaseous hydrocarbons while the mould was being filled. The metal ran freely into the mould, and a good plate was produced, which seemed to be fully as clean on the surface as pure brass. An analysis showed.

Copper,	.	.	.	.	.	.	Per cent
Zinc,	.	.	.	.	.	.	61.09
							38.91
							<hr/> 100.00

The plate was rolled from 0.590 in. to 0.461 in. thickness, without annealing, but no cracks appeared. Annealed and rolled to 0.279 in., it showed a few edge-cracks. Annealed and rolled to 0.051 in., it cracked considerably on the edges.

VI. A COMPARATIVE TEST, SHOWING THE EFFECT UPON BRASS OF OXYGEN IN THE CONSTITUENT COPPER.

The following tests were made to compare the physical characteristics of this alloy with brass made from new materials. For comparison an alloy of the same composition was made, to which treatment was given identical with that which the preceding alloy had received. Pure Lake copper and Bertha zinc were used, and the sheet was rolled down from the same thickness. The results were as follows:

Comparative Statement of Properties of Sheet-Brass Made from Copper Containing Oxide, and from New Copper.

Brass Made from Copper Containing 0.55 per cent Oxygen	Brass Made from New Lake Copper
Analysis of the sheet { Copper, . 61.09 Zinc, 38.91 100.00	Analysis of the sheet { Copper, 61.36 Zinc, 38.64 100.00
Hard-rolled from 0.279 in. without annealing	Hard rolled from 0.343 in. without annealing
Size, 0.0505 by 0.456 in.	Size, 0.052 by 0.474 in.
Tensile strength, 2570 lbs.	Tensile strength, 2736 lbs
Tensile strength per sq. in., 111,500 lbs	Tensile strength per sq. in., 111,000 lbs.
Elong. in 1 in. (fractured section), 4 per cent	Elong. in 1 in (fractured section), 5 per cent
Elong. in 8 in., 1.5 per cent	Elong. in 8 in., 0.75 per cent.
Size of fracture, 0.049 by 0.428 in.	Size of fracture, 0.046 by 0.457 in.
Reduction of area, 9 per cent.	Reduction of area, 15 per cent
Annealed sheet (rolled from 0.590 in. with various annealings) Annealed after slit.	Annealed sheet (rolled from 0.625 in. with various annealings) Annealed after slit.
Size, 0.0505 in. by 0.475 in.	Size, 0.051 by 0.477 in.
Tensile strength, 1476 lbs.	Tensile strength, 1492 lbs
Tensile strength per sq. in., 61,500 lbs	Tensile strength per sq. in., 61,390 lbs.
Elong. in 1 in. (fractured section), 52 per cent.	Elong. in 1 in (fractured section), 52 per cent
Elong. in 8 in., 31 per cent	Elong. in 8 in., 33 per cent
Size of fracture, 0.035 by 0.356 in.	Size of fracture, 0.038 by 0.360 in
Reduction of area, 48 per cent.	Reduction of area, 44 per cent

The comparison of these two samples of sheet demonstrates the fact that there is little if any difference between them. Although the sheet which was made from the copper containing oxygen originally had the same percentage of oxygen contained in the copper as that of Experiment No. 10, yet no salamander was produced, and the sheet behaved nearly as well in the rolls and testing-machine as the purest brass which it is possible to make. The difference in results may be readily explained by the difference in treatment. The copper in the experiment which produced the salamander was melted without charcoal or flux, while the other was carefully treated, both before and after the copper had melted. In the latter sample, therefore, the oxide had been reduced to metallic copper by the excess of charcoal which was present during the melting.

VII. THE EFFECT OF PROLONGED HEATING UPON BRASS SALAMANDERS

Experiment No. 14—In order to ascertain the influence of prolonged heat on the salamanders which had resulted from the various experiments, they were melted together in a covered plumbago crucible, without charcoal or flux; and, after zinc oxide had been given off freely, the heating was prolonged for about half an hour. The mass was then poured out. Although zinc oxide was expelled from the crucible in clouds, only part of the alloy was liquid, the remainder still existed as a salamander. The weight of metal poured out was 4 lbs 10 oz., and that of the remaining salamander was 5 lbs. 4 oz.

The portion poured out did not run sluggishly, but filled the mould as sharply as pure brass. Apparently all the zinc oxide can be driven off from a salamander if the heat be sufficiently prolonged and plenty of reducing material, such as charcoal, be present.

VIII. GENERAL CONCLUSIONS

It is believed that the preceding experiments demonstrate that oxygen in copper, unless present in abnormally large amounts, does not exert a deleterious influence on the quality of brass intended for rolling into sheet. If oxygen is present in excessive amounts (quantities seldom occurring in practice unless the melter is lax in his methods), salamanders are apt to

form. If it is present in less amount, salamanders may not form, but the brass manifests a tendency to crack in rolling. This is due, no doubt, to the zinc oxide present, which prevents perfect cohesion. From still smaller quantities of oxygen, practically no injury is noticed. The proportion may even be as high as 0.55 per cent. (Experiment No. 13) and no adverse results happen; but more than ordinary care must be exercised to keep the metal thoroughly covered with charcoal.

The amount of oxygen in commercial copper is more or less variable, depending upon the caprices of the refiner; but in the best brands great care is taken to keep within as narrow limits as possible. The pitch, of course, determines this point.

According to advices received in personal communications from chemists representing two leading brands of copper on the market (one Lake and the other Electrolytic), the amount of oxygen which exists in these brands of copper may be taken as follows

	Lake Per cent	Electrolytic Per cent,
Oxygen Contained in Ingot Copper,	0.012	0.010

On a careful perusal of the results of the various experiments enumerated above, it may be readily seen that no injurious influence can possibly be exerted by such a small proportion of oxygen as 0.01 per cent. Good sheet-brass was made from copper containing over fifty times this quantity (Experiment No. 13). Although the initial amount of oxygen in copper may be quite minute, and not sufficient to exert any influence on brass, yet if the caster is not cautious, and neglects the frequent additions of charcoal, this small percentage may be increased many times by the oxidizing influence of the atmosphere.

In conclusion it may be said that, unless the amount of oxygen in commercial copper exceeds the figure given above, it cannot, *per se*, be called an injurious impurity.

The Colorimetric Assay of Copper.

BY J D AUDLEY SMITH, CLIFTON, ARIZONA

(Canadian Meeting, August, 1900)

HEINE's "blue test" for copper, as described by the authorities generally, calls for a set of standard colors, and there has been some discussion concerning the relative superiority, for this purpose, of sulphate and nitrate solutions. The whole matter evidently hinges on the preservation of the standard colors in well-stoppered bottles. The apparatus described by G. L. Heath* cannot be much improved, when very accurate readings are required.

The following method was devised for the purpose of doing away with preserved sets of standard colors, by making a fresh standard for each batch of assays. The solutions are prepared in the usual way, each ammoniacal solution being filtered into its separate bottle, and then filled up to the containing-mark and thoroughly mixed. A similar color-bottle, with an "S" etched upon it, to distinguish it from the other bottles, which are numbered to correspond with the samples, is kept to run the standard. About 150 c. c. of water is put into it, and then the amount of acid (sulphuric or nitric) present in each determination, followed by 30 c. c. of ammonia (s. g. 0.90), which should make the mixture strongly ammoniacal.

The liquid is now made up almost to the containing-mark (200 c. c.), say within 1 c. c. The lowest assay is selected first and placed alongside the standard, which, at the beginning, contains no copper. A copper-solution is then dropped into the standard from a burette, and after each addition the bottle is well shaken and compared with the assay-sample. This operation is repeated until the two shades match exactly, when the burette is read and the assay-result is calculated. The assay next in order of depth of color is now taken and treated in the same way, and so on, until the batch is completed. It

* *Journal of the American Chemical Society*, 1897, vol. xix, p. 24

will be found that the volume of the deepest colors is from 1 to 2 c c less than the standard, which has increased by successive additions of copper-solution. This is corrected by adding the necessary amount of water to the assay, just before the last one or two drops of copper-solution are added to the standard.

DETAILS OF THE METHOD.

The copper-solution contains 5 grammes c. p copper per 2000 c.c., and is made by dissolving the metal in a small quantity of nitric acid and diluting, so that 1 c.c. = 0.0025 gramme Cu.

It is convenient to have a syphon-attachment, for filling the burette with this solution.

Tailings-Assay.—One gramme is digested on a hot plate with from 3 to 5 c. c. of HNO_3 , to 3 c.c. of HCl , and 5 c.c. of H_2SO_4 . Rapid heating will soon decompose the mineral; and the treatment should be continued until the sulphur globules which form are quite yellow. Add about 30 c. c. of water; then an excess of ammonia-water (s. g. 0.90). Mix thoroughly and filter hot, through a S. and S. folded filter No. 588 or a very rapid paper. Wash the iron precipitate twice with $\frac{1}{10}$ ammonia-water; then dissolve off again into the original vessel with 5 c.c. of 1 to 1 H_2SO_4 and hot water. By lifting the filter and its contents out of the funnel, then opening it out and washing back the precipitate with a jet into the original vessel, the operation can be performed in less than a minute, and with very little water. The solution is now reprecipitated with ammonia, and the filtrate is combined with that obtained from the first precipitation. One final washing is enough ($\frac{1}{10}$ ammonia) for any material not running over 1.5 per cent. of copper.

Slag-Assay.—One gramme is boiled in a dish with 15 c c of water, then 5 c.c. of HNO_3 is added along with 5 c.c. of 1 to 1 H_2SO_4 . The digestion is carried on until the slag is thoroughly decomposed, and any sulphur globules are yellow. It is not necessary to dehydrate the silica; and as decomposition is immediate, there is rarely any delay at this point. The assay is now treated in the way as described above for the tailings-assay; only, care should be taken to avoid using too large quantities of water in washing and transferring precipitates. A third precipitation of the iron has always resulted in a fil-

trate free from copper when working on blast-furnace slags; but in analyzing high-grade slags, some copper may remain in the second precipitate.

The standard is prepared as already described, and the colors are carefully matched. When one gramme is taken, each c.c. of copper-solution is equivalent to 0.25 per cent. of copper.

The following table shows the results of a batch of assays occurring in the daily work of a large copper-plant, and illustrates what may be expected from the colorimetric assay in a busy office. The samples are varied, consisting of mill-tailings, slags and lean ores. The results are not so close as those given by Mr. Heath in his paper, but he says that his electrolytic assay was made on the solution which he had used for his colorimetric assay. The electrolytic assays tabulated below are separate determinations on a separate weighing of the sample, the copper being precipitated from the acid solution of the ore without any previous separation of iron by ammonia.

Comparative Results of Colorimetric and Electrolytic Assays.

No	Colorimetric Assay		Electrolytic	Remarks
1 .	1	1 02	1 06	Electrolytic deposit dissolved in HNO_3 and determined by $\text{KCN} = 1 04$ per cent.
	2.	1.00		
2	1	0 37	0 43	Electrolytic deposit by $\text{KCN} = 0 73$ per cent
	2.	0 42		
3	1	0 65	0 73	
	2.	0 67		
4 . . .		0 92	0 91	" " " = 0 95 "
5.		1.15	1 13	" " " = 1 14 "
6		0 60	0 68	Electrolytic deposit dissolved in HNO_3 and determined colorimetrically = 0 65 per cent.
7 .		1.35	1 44	
8 .		1 07	1 13	Electrolytic deposit by color = 1 40 per cent
9 .		0 99	1.04	" " " = 1 15 "
				" " " = 1 00 "

Green tints generally result in a low reading. Organic matter is the principal cause; but considerable percentages of arsenic will also interfere, and produce tints which it is impossible to compare. Small percentages of arsenic have no effect.

The advantages of the above method over the usual method of using sets of standard colors are:

1. In a small office space is valuable, and a set of standard colors will take up room which may be used for something else.

2. An exact match is made with each assay
3. The assays are read from a fresh standard, and not from a bottle which may have been made up months before.

It was found that Mr. G. L. Heath's bottle was expensive, and easily broken. A bottle which is inexpensive, stands the wear of the assay-office of a works, and, at the same time, gives excellent results, is a square bottle, No. 5675 of Eimer and Amend's catalogue, 2 in. in diameter, and $4\frac{3}{4}$ in. high from bottom to neck, upon which any required markings for contained volumes can be readily etched, according to the desire of the assayer.

The results tabulated above were obtained with this bottle.

The Explosion at the Red-Ash Colliery, Fayette County, West Virginia.

BY W N PAGE, ANSTED, W VA

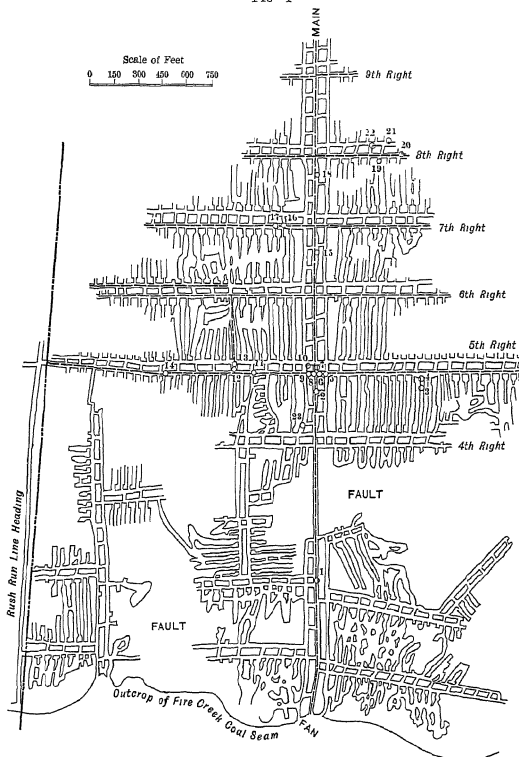
(Canadian Meeting, August, 1900)

THE Red-Ash colliery was the scene, March 6, 1900, of an explosion by which some fifty men were killed or wounded, and much property was injured or destroyed. On March 19th, the earliest date at which entrance was practicable, I examined the mine with the view of determining the extent, cause and point of origin of the explosion, and with the permission of Mr. F. Howald, the manager, and the owners of the property, for whom the examination was made, I present in this paper some results of that examination, comprising the essential portions of my report to them.

LOCATION AND PLAN OF THE MINE.

The Red-Ash colliery, situated on the south side of New river, next below the Rush Run mine, with which the underground workings are connected, is a drift-mine, the entrance to which is on a slope, about 500 ft. above the river. (Fig 1 is a plan of the workings, in which the points where human bodies were found are designated by numbers.)

FIG 1



Plan of the Red-Ash Colliery, W Va The bodies of those killed by this explosion were found at the points designated by numbers, as follows 1, five bodies, 2, three, 3, one, 4, one, 5, one, 6, one, 7, one, 8, one, 9, one, 10, one, 11, five men and one boy, 12, one, 13, two men, 14, one; 15, six men and one boy, 16, one boy, 17, one boy, 18, six men, 19, one, 20, one, 21, one, 22, one, 23, one

The main entry has been driven north about 4000 ft from the surface, with parallel entries on either side from the fourth

set of cross-entries, and about 70 ft. of chain-pillar between the parallels. Except where interrupted by a squeeze—marked “Fault” on the plan, Fig 1—cross-entries have been driven east and west at intervals of 400 ft., with parallel air-ways, constituting a complete double-entry system, remarkably regular and uniform, aside from the squeeze referred to. About 75 ft. west of the entrance, an exhaust-fan, built by Messrs. Thayer, of Charleston, W. Va., is located in the mouth of the parallel air-way on the left or west side of the main entry, which parallel is broken by the squeeze, but connected at the fourth set of cross-entries, through workings to the westward, giving about the same effect as if the air-way had been continuous. I did not measure the efficiency of this fan; but the mine-workings have been planned for an excellent system of ventilation, which should be ample for every requirement, with any standard centrifugal machine proportioned to the work. The fan is driven by compressed air, which is frequently used for such purposes, and I understand that several others of the same model and make are employed in the district, giving satisfactory results. Under the plan of ventilation, the main entry is the intake, with an average cross-section of about 6 by 12 ft., or 72 sq. ft. of area, which is more than enough for the safe working-requirements of the mine. The current is directed to the head of the intake, where it is split, and conducted across the face of the workings to the east and west, through a system of trap doors, brattices and stoppings; that on the east returning through an overcast at the fourth cross-entry. With the double entries and break-throughs from room to room, as shown on the plan, there is no reason why the circulation should not have been as nearly perfect as any artificial system of ventilation can be made, as the entries and air-ways are unusually straight, with ample cross-sectional areas to reduce friction and resistance to a minimum. I feel safe in saying, therefore, that if there was lack of circulation at the time of the explosion, it cannot be attributed to any defect in the system or the general plan of the mine-workings.

EXTENT AND EFFECT OF THE EXPLOSION.

The main entry showed no evidence of unusual heat or flame, beyond what might be expected along the intake, from an ig-

nition of gases in some other part of the mine, the heated air and flame being necessarily thrown toward this entry, as offering the line of least resistance to daylight. Beyond the ninth cross-entries, the force had been exerted toward the face or inward, and from these entries, outward, everything had been swept toward the entrance like shot from the barrel of a gun—to which this entry may be likened, the expanded air and gases in the extensive workings representing those of the enlarged powder-chamber of the gun. From the 5th cross-entry there were three escapes for the pressure they produced, the main entry being the shortest, and the only straight one. A second was the parallel air-way on the west (left) which turned squarely to the west at the 4th entry, and had to pass through the “squeeze” by a devious route, before reaching daylight at the fan, which also operated to obstruct this outlet. The third way was down the west 5th entry to the Rush Run workings. Between these and the Red-Ash there was a brattice, or stopping, which was blown out, and in addition to which there must necessarily have been, in that direction, other resistance due to old workings.

The walls and roof of the main entry were covered with white dust from the floor, showing that the clay in the tracks and road-beds had been swept out through this channel with considerable force. At the 4th cross-entry the overcast timbers were blown straight down, showing that the contracted area of the stone drift through the squeeze had dammed back the force and equalized the pressure from the east workings, the return from which was through the overcast at this point.

The 4th cross-entry east shows the effect of heat, as if it had been filled with flame, the ribs and roof being covered with coked dust. The indications here also point to the conclusion that the forces were dammed back by the stone drift, which probably gave the flame more time for action. At the 5th, 6th, 7th and 8th cross-entries the doors on the west were blown in, and down the main entry, toward daylight; while those on the opposite side were thrown eastward, toward the faces of the workings. The door of the 8th west entry was found several hundred feet down the main entry, toward No 7,

and the six men found at point 18 on the plan, as well as the cars wrecked there, evidenced a violent force from the west, coming down this 8th cross-entry. On the main entry at No 2 west, five bodies were found badly mangled and burned. As this point is near the beginning of the stone drift, the force and heat were probably concentrated by the contracted area inside, but had room to expand through the old workings toward the outcrop, before reaching the entrance. At points 2, 5, 6, 7, 8, 9 and 10, at and near the intersection of the 5th cross-entries with the main, the bodies of nine men were found. Two were found at points 3 and 4 on the 11th room of No 5 east, and on the same entry west, six were found at 11, one at 12, two at 13, and one at 14. The body of a boy was found in the west airway, between cross-entries 4 and 5. It is possible that he was blown there from No. 5. No. 5 east showed heat and coked dust due to flame, but little effect of the explosive force, which appears to have been directed up the entry, from the main, to the 8th or 9th room. Enormous forces were exerted down the 19th and 20th rooms, coming from the direction of No. 4, with which they were connected by break-throughs. The tracks and everything movable, including a Harrison mining-machine, were thrown out of these rooms against the rib of No 5 entry, where the force seems to have been divided, one part being directed toward the face of the entry, the other toward the main entry. There are only two ways of accounting for this curious reversal of forces. One is, by supposing that a local pocket of gas was fired, and followed the line of least resistance, which must have been toward No. 5, possibly on account of the stone drift; and the other is the assumption of a secondary or later explosion, due to either a pocket of fire-damp, or of carbon monoxide, known as "white-damp" by miners, which might have been produced by reduction of the carbon dioxide, or "black-damp," passing over the red-hot carbon, of the presence of which there is ample evidence in both the 4th and the 5th entries. A molecule of carbon dioxide (CO_2), in passing over red-hot carbon (in this case, coke) takes up another atom of carbon in chemical combination, making two molecules of carbon monoxide (2CO), which is a combustible (and when mixed with air before ignition, an explosive) gas, being the

principal constituent of the furnace-gases used for heating the blast and boilers at all modern iron blast-furnaces. The latter alternative strikes me as the more reasonable, as the partial vacuum, created by the first explosion, would have directed the line of least resistance from these rooms inward, or toward No 5, a fact hard to account for without such a partial vacuum. As a further evidence that there was little resistance from within, this force seems to have been expended to the east, before reaching the face of the entry, near which a car was found standing on the track, with a sheet of white paper stuck in the side, neither of which had been disturbed; consequently the direction of least resistance must have been westward and inward.

Entries 6 and 7 east, as already observed, had their doors blown eastward, showing that the force originated in or beyond the main entry, and not in these east workings, in which there is little evidence of violent disturbance, though coked dust on the walls and roof shows flame and heat. No. 8 east was little disturbed by heat or force, especially near the faces of the workings, and I am confident that the explosion did not originate in these or any other workings east of the main entry.

The body of a man was found on No 8 east at point 19, in the mouth of the fifth room, to reach which he must have passed within sight and hearing of the fire-boss, who was found at 20, only about 100 feet distant, on the same entry, at the 7th room, and 5th break-through. It is evident that the latter had found gas in the face of this entry, as he had raised the end of the air-pipe and turned on the air, to drive it out; but it is reasonable to assume that he did not regard it as dangerous, or he would not have permitted the presence of the three men found so near, one at 19, one at 21, and one at 22, all of whom he probably saw or heard enter. I was informed that none of these four men were burnt or disfigured, and from descriptions of their position and condition, I infer that they must have been killed by the after-damp resulting from the explosion.

On the air-way between points 21 and 22 a powder-keg was found, sitting in a tool-box, which looked as if it might have

been opened out by an explosion of the powder, but a careful examination convinced me that this theory was untenable. Machine-runners and trimmers usually open old powder-kegs in this manner for use in shielding their lights from the coal-chippings thrown out by the machine, and I am convinced that this keg had been prepared for that purpose and put in the box for safe keeping. Had the gas-explosion originated from powder in this keg, the effects along the main entry from its intersection, to the squeeze, would have been reversed.

The faces of the main, parallel, and cross-entries No. 9 all show the effects of considerable force, coming up the west parallel from No. 8, and the intersection of this parallel with No. 9 west is indicated as the point at which the greatest force of the explosion was exerted within the mine. On entry No. 8 west, near the mouth of the second room shown in Fig. 1, the waves of force were projected in every direction, the track and timbers having been thrown east and west on the entry, and north and south through the rooms and air-ways. As no other point in the mine exhibited like conditions, it is reasonable to assume this as the origin of the explosion; and, in my opinion, the gas was first lighted at or near this point. Everything was swept through this room to No. 7 entry with great violence; the indications being that the forces directed south through this room, east to the main entry, and north up the parallel air-way, were about equal, while that along the entry to the west was breeched by the faces of the workings, distant only a few hundred feet in that direction. All indications in the west workings point to the movements of the forces from that point to daylight along the lines of least resistance, through rooms, air-ways, and main entry, and along No 5 west, in *both* directions, eastward to the main entry, and westward to the Rush Run mine. At point 16, on No. 7 west, a boy was found in line of the room already referred to, leading from No. 8, and I saw a pool of blood and brains where his head had rested. Near by, at 18, another boy was found. The workings being extensive, there were large areas to receive the expanded gases, and a considerable portion of the forces had evidently been thus dissipated by the time they reached No 5 cross-

entry, otherwise, the fan would probably have been demolished.

CAUSE AND ORIGIN

The primary cause of the explosion was evidently fire-damp, a carburetted hydrogen gas, the principal constituent of which is CH_4 , or marsh-gas. We know that a mechanical mixture of more than one part of this gas to 14 of atmospheric air is explosive—the most explosive proportion being about 1 9.5. With more than 15 or less than 5 parts of air to one of gas, the mixture is not explosive, but by reason of the diffusion of gases, this mixture must always be found variable where there is any ventilation or circulation of air. As all coal will give off at least its own volume of gas (and some coal much more), its presence is easily accounted for, and would be detected in all coal-mines, but for its tendency to escape through every crack and crevice toward higher outlets, owing to its density being less than that of air. Taking the density of air as unity, that of methane, or marsh-gas, is 0.559, or a little more than one-half as great. If sufficient time is allowed, air and fire-damp will make a complete mechanical mixture, according to the law of diffusion of gases; but the latter is usually found at the top in mine-workings, owing to lack of time for complete diffusion, before the gas is removed by natural or artificial ventilation. In coal-mines above water-level, where the covering can crack, or break, fire-damp is rarely noticed in workings within less than a mile of the escarpment, or outcrop. Within this limit it is carried off by the usual methods of ventilation, assisted by the movement of cars, the upward escape by levity, through crevices, etc., but below water-level, or where the lines of escarpment embrace larger areas, with a heavy, unyielding cover, gas may usually be expected to give more or less trouble.

At Red Ash there is no escarpment northward or westward, in the direction of the workings, for many miles, and the overlying rocks are too massive to break, in consequence of which gas had been found within 4000 ft. of the entrance, and was probably given off freely in all the workings inside, and including the 8th cross-entry. During a period when the fan was idle, on Monday night, there must have been in these

workings an accumulation of gas and a mixture of it with air, which by the operation of the fan on Tuesday morning was started back in the return air-course, where it was met by a naked light on the 8th west entry near the main return air-way. About sufficient time (30 minutes) had elapsed, since the starting of the fan, for the air to travel down the intake, 4000 ft. of the main entry, and back on the return to the point indicated—the total travel being about 4500 ft., which would make the velocity about 150 ft. per minute, and (taking the section of main entry at 72 sq. ft.) would be equivalent to a volume of nearly 10,800 cubic ft. per minute,—probably as much, or more than as much, as the fan was doing on the start.

The theoretical requirements for ventilation given by André, in his "Practical Treatise on Coal Mining," a standard authority for the world, are 24 cub. ft. of air per minute for each man and light, 72 for each horse, 192 for each pound of powder burned, 100 for each cub. ft. of coal mined, and 1 cub. ft. per minute for each square yard of coal-surface in the mine.

Assuming that 150 men were employed underground in the Red-Ash colliery, with 15 horses or mules; that 12 lbs. of powder were burned per hour, and 18 cub. ft. of coal were mined per minute (or 400 tons in 10 hours); and that 1000 square yards of coal-surface was exposed, a simple calculation will show that 10,000 cub. ft. of air per minute would be required to satisfy André's requirements. But this would leave no factor of safety, whereas such a factor, of 2 to 5,—according to actual tests of the amount of gas produced in the mine,—should be allowed.

From the effects observed, I think the dust had little or no influence on the primary cause, though it must necessarily play an important part in all explosions, when the gas is once ignited, by adding to the forces evolved. My impression is that the boy found on No. 7 west, at 16, met the gas with a naked light in No. 8 west, on its return to the fan, and was blown down the room to the point where his remains were found. It is possible that one of the men found at 18 on the main entry may have lighted the gas in the return west air-way at or near its intersection with No. 8 cross-entry, in which event the force ex-

erted at that point was sufficient to have blown him to where these bodies were found. From all the evidence, however, I am inclined to the opinion that the gas was lighted by the boy found at 16, as he was in a straight and direct line from the evident point of ignition, indicated by circles of force, like the ripples from a stone thrown into a pond of still water; and at every other point in the mine the forces can be traced to this origin as the center from which the waves emanated. I was satisfied, from all I could see and hear, that the general plan and conduct of this mine were fully up to the standard of the New River district, and above the average in many respects. The presence of gas in dangerous quantities, however, was not fully realized, consequently some of the expense and precautions for a highly gaseous mine were omitted. Nor could the precautions necessary for such conditions have been instituted, in my opinion, without a loss at the prevailing market prices, as the additional costs would necessarily have exceeded the profits.

Both the operators and operatives of this district are unaccustomed to gaseous mines, and both must be educated to the requirements. The operator may comply strictly with every requirement, regardless of cost; yet the ignorance or carelessness of a single operative may bring about disaster without warning, and none may live to tell the tale. Many such cases are on record, and nothing but time, strict attention, and experience, will provide an adequate remedy.

As already observed, I did not measure the volume of air handled by the fan during my visit. Under the conditions as I understand them, however, the capacity of the fan would have had little effect upon the result, as it was not running more than thirty minutes before the explosion. The larger the capacity of the fan, the sooner the gases would have been drawn out and the mine rendered safe; but the danger existed as long as they remained in the return, where they were liable to ignition anywhere between the fan and the working-faces where they had been generated or accumulated.

The Electromotive Force of Metals in Cyanide Solutions.

BY S. B. CHRISTY, PROFESSOR OF MINING AND METALLURGY, UNIVERSITY OF CALIFORNIA.

(California Meeting, September, 1899)

THE practice of the cyanide-process of gold-extraction has brought to light many important contradictions of familiar chemical analogies, which still obscure both the theory and the practice of the art with distinctions subtler and more difficult to make or follow than those which delighted the heart of the old-time metaphysician. Yet Nature herself has drawn these distinctions; and if we hope to succeed in this modern search for the Golden Fleece, we must be able to follow her through the winding labyrinth.

There are so many phases of this question that I shall attempt to touch on only one of them at this time, but it is one that lies at the root of many others.

In reviewing my paper on "The Solution and Precipitation of Cyanide of Gold,"* Mr. E. B. Wilson contends† that "in the solution of gold by means of alkaline cyanides the various reactions are determined, as to their order and intensity, by the relative position of the elements concerned in the electro-chemical series, or series of voltaic tension."

In a modified form this statement is probably true. That is to say, the difference of electrical potential in any closed electrical circuit determines the nature of the reactions which ensue. But the matter is not so simple as Mr. Wilson assumes. Recent investigations show that the order of the metals in the electro-chemical series depends not only on the nature of the elements themselves, but also on the chemical composition of the solution in which they are placed, its degree of concentration; its temperature; and, in the case of gases, on the pressure.

Unless all these conditions are taken into account, inferences drawn from the electro-chemical series are likely to prove more

* *Trans.*, xxvi, 735

† *Trans.*, xxvii, 821

misleading than useful. The series, as quoted by Mr. Wilson from Gore, is as follows

3 Potassium	28 Antimony
4 Sodium	29 Tellurium
8 Calcium	31 Gold
9 Magnesium	37 Carbon
12 Manganese	39. Nitrogen
13. Zinc	40 Arsenic
15 Iron.	43 Sulphur
20 Lead	45 Bromine
24 Copper	46 Chlorine
25 Hydrogen	47. Oxygen
27 Silver	

This series correctly shows the difference of potential in many solvents, especially in acid solutions, but the use of it for predicting the action of cyanide solutions involves several grave errors, one of which is the assumption that the nature of the solution in which substances are placed is without effect on the order of the series.

The remarkable effect of solutions of cyanide of potassium upon the relative positions of substances in the electro-chemical series was first shown by Prof. Jacoby, who, on August 21, 1844, called the attention of the St. Petersburg Academy of Sciences to the fact that when silver and cyanide of potassium solution replace the zinc and sulphuric acid in the Daniell cell, a strong current ensues and copper is precipitated. Ordinarily, and according to the usual inference from the above series, copper precipitates silver from its solutions, but here was a combination in which silver precipitated copper.

In the following year, Poggendorff announced* that by his (now well-known) "compensation-method," he had found the electro-chemical series in 1 part of KCy to 8 parts water—*i.e.*, in a 12.5 per cent. solution of KCy, to be—

1. Zinc amalgamated	9 Lead
2 Zinc	10 Quicksilver
3 Copper	11. Palladium
4 Cadmium	12 Bismuth
5 Tin	13 Iron
6. Silver	14 Platinum
7 Nickel	15. Cast Iron
8 Antimony	16 Carbon (<i>Kohle</i>)

* *Annalen*, Bd. 66, s 597, 1845

Gore also* investigated this subject with similar results, only he showed that the order depends on concentration and temperature; and that, according to these conditions, gold may be more or less electro-positive than silver.

The variations thus discovered in the relative position of the metals in the electro-chemical series at once cast a cloud on its usefulness for predicting chemical reactions, and though a great mass of experimental data was accumulated, and the most acute minds of the century were brought to bear on the problem, no explanation of these anomalies was found for many years.

It is only within the last decade that anything like a clue to the mystery has been detected, and this result has been made possible only through the combined efforts of a number of men who approached the subject from what may be almost termed its purely speculative side, without any thought of practical applications

Now that something tangible seems to be resulting from these efforts, I have thought that a brief outline of the rapid progress made in the electro-chemical theory during the last decade might be of service to those who have been too much occupied with practical details to follow theoretical investigations for themselves. Such an outline will also render more clear the bearing of the experimental work which follows.

I—OUTLINE OF THE DEVELOPMENT OF THE MODERN ELECTRO-CHEMICAL THEORY

Analytical Research.—In the development of this subject, the efforts of investigation in the line of pure mathematics have been combined with the experimental methods of the chemist and the physicist with the happiest results.

Chief among the mathematicians in this particular field is Prof. J. Willard Gibbs, of Yale University, whose work is too little known and appreciated by his countrymen, or even by his own colleagues. His essays, published in the *Transactions* of the Connecticut Academy of Science, being purely mathematical, attracted but little attention in this country, but, being translated into German by Prof. Ostwald, were introduced to a public capable of appreciating them. He is now recognized in

* *Proc Royal Soc.*, Lond, vol xxx., p 45, 1879

Europe as having anticipated many important discoveries with which Helmholtz had been credited. His predictions concerning the laws governing matter and energy have been verified as far as they have been tested, and are even yet far ahead of experimental verification. It is impossible to give here an adequate account of the work of this great man, but he will always be recognized as a leader in the application of mathematical analysis to the most profound physical and chemical problems.

The "Ions"—While Gibbs and Helmholtz were busy with the mathematical side of the question, Daniell, Kohlrausch, Hittorf and many others were busy in following the experimental lines opened up by Faraday. Faraday had always assumed that the electric current was transported through a solution by discrete particles of matter, each bearing its own electric charge. To these moving particles of matter he gave the name of "ions." Those which move in the solution in the same direction as the positive electricity he called "cations," and those which move in the opposite direction, "anions." The electrodes he distinguished as the "cathode," to which the cations move, and the "anode," to which the anions move. These distinctions have proved of the greatest service; their value and meaning have been made yet more clear by the work of Daniell, and most of all by the classic experimental researches of Hittorf. The latter showed beyond question that the passage of the current was accompanied by an actual transfer of the cations and anions through the solution in opposite directions. He and those who followed him were able to determine that these ions were sometimes simple elements, like sodium, potassium, silver, copper, etc., and at other times compound molecules like SO_3 , NH_3 , NO_3 , etc. Thus, while common salt would have for its cation sodium, and for its anion chlorine, sodium nitrate would have for its cation sodium, and for its anion NO_3 . He proved these propositions by ingenious experimental methods which are still admired for their simplicity and certainty.

Hittorf showed also that, in the case of potassium argencyanide, the principal cation was not silver, but potassium, which alone traveled in the direction of the positive current. The silver traveled in the opposite direction, with the cyanogen

and the negative electricity, and formed the anion (AgCy_2). He explained the reduction of the silver which takes place at the cathode by proving that all (but a trace) is due to the secondary reaction which ensues when the potassium ion is deposited at the cathode and displaces an equivalent of silver from the silver cyanide there adjacent.

This experiment is so important that it will be considered more extensively below. It is sufficient in this place to say that he proved that, while an equivalent of silver was deposited at the cathode, the adjacent solution was robbed of that equivalent, and at the same time there was found an extra equivalent of potassium in the form of caustic potash, while about the anode there was an increase of one equivalent of silver and two equivalents of cyanogen. The conclusion is irresistible that the principle ions are, cation (K), anion (AgCy_2). He proved also that the ions migrate with different, moderate and easily measured velocities.

Molecular Conductivity.—Meanwhile Kohlrausch, Ostwald and others were making a tedious and apparently useless investigation on the electrical conductivity of solutions of increasing dilution. The specific conductivity of dilute solutions is usually much smaller than that of more concentrated ones, but when the comparison was made on the basis, not of specific, but of molecular conductivity, a new and important law was discovered.

For the purpose of comparing the molecular conductivities of solutions, a unit known as the "gramme-molecule" was employed. A given volume v of solution is said to contain a "gramme-molecule" of a given substance whenever it contains a number of grammes of the substance equal to its molecular weight. Thus a "gramme-molecule" of potassium cyanide would be 65 grammes supposed to be dissolved in v liters of water. When v is one liter we should have a solution of one "gramme-molecule" per liter. In this case, for univalent substances, the "gramme-molecule per liter" is of course identical with one "equivalent" or a "normal solution."

Now, when we compare the total conducting power of a gramme-molecule of all electrolytes, we find that, as the volume v increases, and the solution becomes more dilute, the total, or molecular, conductivity of the whole volume of solution in-

creases instead of diminishing with dilution, as the specific conductivity does. This increase is at first quite rapid, then the conductivity becomes nearly constant and increases only very slightly, to reach its maximum value for $v = \text{infinity}$.

Kohlrausch proved by a comparative study of these results that the total conductivity of a dilute solution is due to the velocity of the ions, and also that it is made up of the sum of the velocities of the cathions and anions moving in opposite directions.

Osmotic Pressure.—Meantime progress was being made in an apparently totally different field. Pfeffer, professor of botany at the University of Leipzig, made an extensive study of the osmotic transfer of solutions through the walls of plant-cells, and devised in 1878 a method by which it was shown that osmotic action was capable of producing certain definite pressures. His method consisted in using a "semi-pervious membrane" through which the solvent, but not the solid in solution, can pass. When, for instance, a glass tube, closed at the bottom with a plug of porous earthenware coated with the semi-pervious membrane of ferrocyanide of copper, is filled with a strong solution of sugar and the lower end is placed in distilled water, the latter, being able to pass through the pores of the filter, does so; while the sugar particles, being unable to pass out, remain in the tube, and hence the solution column actually rises in the tube. Pfeffer showed that the pressure, as measured by the height of the column, was proportional to the amount of sugar in the solution and increased with the temperature.

The Gas-Law and Osmotic Pressure.—These phenomena had long been supposed to be due to an attraction of the sugar for water; but the fact that the osmotic pressure was proportional to the sugar-content, and increased with the temperature, suggested to Prof. Van't Hoff, the brilliant Hollander, that the dissolved substance acted just as a gas would do.

His reasoning was something like this. A dissolved substance exerts an osmotic pressure against the bounding surface of the liquid, just as a gas does against the walls of the vessel that contains it. But the surface of the liquid presses inwards with a pressure of above a thousand atmospheres (the *Binnen-druck* of the Germans, which prevents the liquid from evapora-

ting instantaneously into space). This surface-tension of the liquid resists the comparatively slight osmotic pressure, and ordinarily the latter produces no noticeable effect.

But when a semi-pervious membrane, through which water may pass, but which will filter out the sugar molecules, is interposed between the sugar solution and the clear water, the pressure of sugar molecules against the semi-pervious membrane and the upper surface of the solution raises the latter just as it would a piston; and as the sugar is unable to exert any pressure on the surface of the water on the other side of the semi-pervious membrane, the clear water freely enters the tube through the membrane as fast as the upper surface rises.

Of course, according to the gas-law, the osmotic pressure should increase with the concentration. Hence Van't Hoff applied the gas-law, $pv = RT$, in which p represents the pressure, v the volume containing a gramme-molecule; T , the absolute temperature, and R , the "gas-constant." When this formula was applied to Pfeffer's results an almost perfect agreement was discovered, and the same result was obtained with numerous other solutions of *organic substances*. But when it was applied to inorganic salts, or electrolytes, it was found that the osmotic pressure was greater than that indicated by the molecular concentration. Van't Hoff expressed this fact by the formula, $pv = iRT$, in which i is a coefficient greater than unity.

Here was an apparent anomaly; the osmotic pressure was apparently greater than that due to the number of molecules, that is, greater than the gas-law would indicate. Progress seemed to be stopped by a stone wall. But it was not delayed long.

Dissociation.—Arrhenius, the masterly Swedish physicist, suggested a new idea. Perhaps the gas-law still holds, only the number of molecules has been increased by the dissociation of some of the dissolved substance. If a part of the molecules were supposed to be split, so as to double their number, the total number of molecules present would be increased and the gas-law might still hold. It was soon shown by Arrhenius that there was a close relation between the size of the coefficient i and the "chemical activity" of the substance. For instance,

in the case of the inorganic acids, this coefficient was particularly large in those chemically most active, like hydrochloric and nitric acids. Assuming that in these cases the dissociation was most complete, he made another brilliant generalization. He distinguished between "chemically active" and "inactive" molecules, and claimed that the dissociated molecules were the only "chemically active" ones. This distinction has proved to be sound.

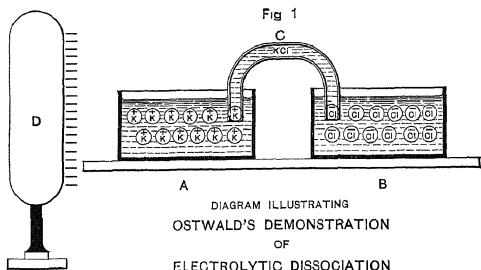
The next step was to show that the increase of molecular conductivity of dilute solutions was due to this same dissociation, and that the dissociated molecules alone took part in the transfer of the electrical current. Arrhenius concluded that the dissociated molecules formed the "ions" which Faraday had shown to be instrumental in conveying the current; that each dissociation produced a cation which carried the positive electrical current, and an anion which carried the negative current in the opposite direction; that these alone were active in the electrical transfer; that when a substance was entirely undissociated it would be a non-conductor, and that its conducting power was directly proportional to the number of ions present.

This view was strongly contested at first. It was argued, in opposition, that such strongly combined substances as, for instance, potassium chloride, could not possibly split up in solution, even in part, into potassium and chlorine ions—that the potassium would decompose the water. But the reply was "What if it did? The only effect would be to produce HCl and KHO ; these would again dissociate into H and Cl and K and HO ; and the potassium and chlorine ions would still exist as before." It was also suggested by Prof. Ostwald, of the University of Leipzig, that the ions were an allotropic modification, different from the ordinary elements, in that to the cation was attached a positive charge, and to the anion an equal negative charge, of electricity; and that when these electrical charges were given up at the electrodes, the ions changed into the ordinary elemental form.

Ostwald was the first to defend these new views, and the position now held by the theory is largely due to his remarkable genius for outlining, executing and interpreting experimental work. Together with his students, inspired by his example, he has accomplished a great work in clearing up many difficult points as fast as they were raised.

Fig. 1 illustrates an ingenious experiment devised by Ostwald to show the bearing of the new theory. Two vessels, A and B, filled with a solution of KCl , are connected electrically by the column of solution contained in the siphon C. If the theory be correct, a large insulated conductor D, charged with negative electricity, and brought near the vessel A, will act by induction on the ions contained in A and B. The electrically positive, potassium cations, will migrate through C and collect in A, being attracted by the negative charge on D. At the same time the electrically negative chlorine anions, repelled by the negative charge on D, will accumulate in B.

On removing C, so that A and B are disconnected electrically, and then removing D, the vessel A will contain an excess of posi-



tively electrified potassium ions, and the vessel B an excess of negatively electrified chlorine ions. So long as the vessels are not connected with each other or the earth, they will inductively remain in equilibrium and there will be no reaction between them. But according to the theory, if their contents be connected by a platinum wire, the potassium ions will give up their positive charge on the end immersed in A (hydrogen being set free by the reaction of the potassium on the water as soon as the ions have given up their electric charge), and the chlorine ions will give up their negative charge on the end immersed in B (ordinary gaseous chlorine being similarly set free on that end of the wire).

The above experiment is difficult of actual execution on account of the enormous amount of electricity (96,540 *coulombs*)

required by each gramme-molecule, but in a modified form of it, using a capillary mercurial cathode, Ostwald and Nernst were able to demonstrate the correctness of this view by traces of hydrogen, distinctly visible under the microscope.

Fig. 1 is therefore not so much a record of actual experimental demonstration as an ideal diagram, serving to explain the nature of the conception involved

Altered Freezing and Boiling Points—Another important confirmation of the ideas of Arrhenius came from an entirely different quarter. It had long been known that the boiling point of an aqueous solution was raised and its freezing point lowered in proportion to its molecular concentration; and the method had even been used to determine molecular weights in cases of doubt. But here again dilute solutions proved an exception, showing variations in excess of what was due, according to the rule, to their molecular concentration. But when the behavior of dilute solutions was examined in the light of the new theory, it was found that the assumption of an increase by dissociation in the number of molecules present explained in these cases, also, the apparent anomaly. That is to say, when the rise of boiling and fall of freezing points of dilute solutions were expressed in terms of the total molecular concentration (allowing for the increase in number of molecules by dissociation, as determined by the method of electric conductivity), the observed facts accorded with the rule

Heat of Neutralization.—Another argument in favor of the dissociation hypothesis is furnished by the remarkable fact that the heat of neutralization of a gramme-molecule of all dilute acids is the same. When strong solutions of acids are neutralized with strong solutions of the several alkalis, the heat of the reaction per gramme-molecule is usually quite different; but when dilute solutions are used, the heat of neutralization per gramme-molecule is found to be practically the same for all the electrolytic salts

This fact, inexplicable according to the usual views of chemical affinities, is a natural consequence of the dissociation-theory. The heat of combination in all these cases is practically equal to that due to the formation of a gramme-molecule of water—that is, to the combination of the atom of H in the acid with the molecule of OH in the alkali. The O and OH ions existing in

water are infinitesimal in amount. Hence, when two solutions containing both in equivalent amounts are brought into contact, they unite, and the heat produced results from their combination. No heat results from the combination of the acid and alkali radical, because they were separated into ions before neutralization, and remain in the same state afterwards.

Hence, as the heat results solely from the reaction $H_2 + O = H_2O$, according to the new theory, it ought to be the same for all dilute solutions of acids and alkalis.

Solution-Pressure—Professor Nernst, now of the University of Goettingen, made the next great forward step in explaining the anomalies in the electro-chemical series. He investigated very carefully the so-called "concentration-cells." The concentration-cell contains two electrodes of the same metal, each immersed in a solution of the same salt of the metal of its electrodes; the only difference between the solutions being that one has a greater molecular concentration than the other. When such a cell is arranged like a Daniell cell (except that both electrodes are, say, of silver, one immersed in a normal, the other in a deci-normal solution of silver nitrate), and the electrodes are connected, a current of electricity results. From the electrode immersed in the dilute nitrate solution an equivalent of silver is dissolved, and at the same time on the electrode immersed in the concentrated solution an equivalent of silver is precipitated. The positive current flows from the electrode in the weak solution to that in the strong solution.

An electric current is thus produced from two electrodes of the same metal immersed in its own salt. Evidently, therefore, it can no longer be deemed necessary to have two different metals, or even the salts of two different metals, in order to produce a galvanic couple. But whence comes the electromotive force in this case?

An attempt to answer this question led Nernst to propose the brilliant hypothesis which commonly bears his name and rounds out the modern theory of electromotive force. Briefly stated, it is that, for a given temperature, each metal has a certain definite "solution-tension," as he first called it, or "solution-pressure," as it has been more aptly named by Ostwald. According to Nernst's idea, every metal immersed in a solution containing none of its ions possesses, at a given temperature, a cer-

tain "solution-pressure" with which its particles tend to go into solution and assume the ionic state. In doing this, each takes from the remaining metal a charge of positive electricity which it imparts to the solution. At the same time the remaining metal receives an equal charge of negative electricity. This causes the formation of Helmholtz's "double layer" of oppositely electrified particles on the surface of the metal, and the process goes on until the attraction of the positively electrified ions for the negative metal just balances the solution-pressure of the metal. By reason of the enormous electrical charges of the atoms (96,540 *coulombs* to the gramme-molecule), it follows that only unweighable traces of the metal have to go into solution to bring about this equilibrium, which, once assumed, remains, unless a charge of positive electricity be imparted to the negatively electrified metal. When this is done, as happens when the circuit of a galvanic battery is closed, the formation of ions and the solution of the metal go on continuously. On the other hand, when a metal is immersed in a solution already charged with its own ions, these at once set up an osmotic pressure opposite to the solution-pressure, and hence, dependent on the concentration of the solution, there are three possible cases

1. The osmotic pressure of the ions already in solution may be less than the solution-pressure of the metal. Here the case is similar to the one described above, but the difference of pressure will be smaller than when no ions were originally present in the solution.

- 2 The osmotic pressure of the ions in solution is exactly equal to the solution-pressure, and no double layer or difference of electrical pressure results between the metal and the solution. In this case the metal remains indifferent to the solution.

3. The osmotic pressure of the ions already in solution is greater than the solution-pressure of the metal. In this case the ions in solution tend to precipitate themselves on the surface of the metal; and at the same time they impart their charge of positive electricity to the metal, which becomes positively electrified, while the solution which had contained an equal number of positive and negative ions becomes negatively electrified. This soon produces a new double layer of oppositely electrified ions, which brings about an equilibrium, unless

a continuous stream of negative electricity is imparted to the positively electrified metal (as by completing the circuit of a galvanic battery), when the precipitation of the ions goes on continuously. The equilibrium of the double layer is brought about (for the same reason as given before) by the precipitation of unweighable traces of the ions.

According to this view, the electromotive force of a galvanic cell is just as much due to the difference of pressure between the metals tending to assume the ionic state, and the ions tending to assume the metallic state, as the force of a steam or compressed-air engine is due to the differences between the steam- or air-pressures acting on either side of the piston.

Hence, Nernst applied the laws of thermodynamics, which had been already worked out so thoroughly for gases, to this problem also, and with the most remarkable results. It is impossible to enter here into all the refinements of the subject; but the following condensed statement will give an idea of the reasoning involved.

Starting with the well-known gas-law

$$(1) \quad pv = RT$$

(p and P being pressures in grammes per square centimeter; V and v , the corresponding volumes in ccm. to contain one gramme-molecule; T , $273 + t$ degrees Centigrade, and R , the "gas-constant" = 1.96 calories), we can easily determine the maximum amount of work, A , in gramme-centimeters, done by a perfect gas, expanding at a constant temperature from a volume v to a larger volume V , and at the same time falling from a pressure P to a smaller pressure p . We have

$$(2) \quad A = \int_p^P v dp.$$

But, from (1), $v = \frac{RT}{p}$; hence

$$(3) \quad A = RT \int_p^P \frac{dp}{p};$$

and, integrating this, we have

$$(4) \quad A = RT \text{ nat. log. } \frac{P}{p}.$$

If we now suppose the gas-law to apply to the diffusion of the ions from the electrode into the solution, let P represent the "solution-pressure" and p the "osmotic pressure" of the ions of the given metal in solution, and further assume that work is done only in falling from the pressure P to the lower osmotic pressure p , and not in changing from a solution-pressure P to an equal osmotic pressure P , it follows that equation (4) will apply directly to this case also

But we can also express the maximum work A in electrical units. If we assume that to a "gramme equivalent" of a univalent element is given its unit charge of $e = 96,540$ coulombs of electricity, and represent by the Greek letter π the potential difference in volts between the metal and the solution, we may also represent the work A done, by the product πe . Hence we have

$$(5) \quad \pi e = RT \text{ nat. log } \frac{P}{p},$$

or, changing, for convenience of calculation, from natural to common logarithms, we have

$$(6) \quad \pi e = \frac{RT}{0.4343} \log \frac{P}{p}, \text{ and hence}$$

$$(7) \quad \pi = \frac{RT}{e \times 0.4343} \log. \frac{P}{p}$$

Now $R = 1.96$ calories, or, in electrical units, $R = 1.96 \times 4.24$, $e = 96,540$ coulombs, and for ordinary temperatures $t = 17^\circ \text{C}$ or $T = 273 + 17 = 290^\circ \text{C}$. Substituting these values, we have

$$(8) \quad \pi = \frac{1.96 \times 4.24 \times 290}{96,540 \times 0.4343} \log. \frac{P}{p} = 0.0575 \log. \frac{P}{p} \text{ volts.}$$

For ions that have a valency $n > 1$, each gramme-molecule will require $n \times e$, or $n \times 96,540$ electrical units, and this must be substituted in the formulas (5) to (8) instead of e , when this is done we have the general formula

$$(9) \quad \pi = \frac{0.0575}{n} \log. \frac{P}{p} \text{ volts.}$$

This formula, of course, is only true for $t = 17^\circ \text{C}$.

I have plotted this curve in Fig. 2. It will serve for any metal in which the ratio $\frac{P}{p}$ is the same. If we study the ratios of $\frac{P}{p}$ we see that when P is greater than p , π always has a positive value, that is, the liquid is positively electrified by the ions which go into solution, and the remaining mass of metal is, in consequence, negatively electrified. As a further consequence, when $p = 0$, $\frac{P}{p} = \text{infinity}$; hence $\log. \frac{P}{p}$, and hence π , equals infinity.

This, of course, is interpreted to mean that a metal brought into the presence of a solution containing none of its ions would have an infinite potential with regard to that solution, but this could only last for an infinitesimal period, after which the liquid would be impregnated with the ions of the metal. Experiment shows that none of the metals give an infinite potential in any known solution. It follows, therefore, that traces of the ions of all the metals must exist in all solutions, even though they may not be recognizable by any other chemical or physical test. The same mathematical difficulty exists with regard to the conception of a perfect vacuum, and a similar conclusion may be drawn, namely, that such a thing as a perfect vacuum is physically impossible.

When $P = p$, then $\frac{P}{p} = 1$, and $\log. \frac{P}{p} = 0$. In this case, the potential is 0, and there is no tendency either to dissolve or to precipitate the metal.

When P is less than p , $\log. \frac{P}{p}$ is negative, and the solution is negatively electrified, owing to the positive ions precipitating themselves with their positive charges upon the metal, which becomes positively electrified. If p could become infinity, $\log. \frac{P}{p}$ would become minus infinity. As a matter of fact, these values are never reached, for the simple reason that as p depends on the number of ions in a unit-volume, it follows that, on dilution, p reaches nearly a maximum value for very moderate dilutions, when dissociation of the liquid is nearly complete, and, after that, the value of p is reduced rather than increased by further dilution.

According to this view, the electromotive force of the metals in their solutions depends, for a given temperature.

1. Upon the "solution-pressure" peculiar to each metal.

2. Upon the number of ions of the given metal present in the solution in which it is immersed.

If the "solution-pressure" peculiar to each metal were accurately known, we might write out an absolute electromotive series for the metals. Le Blanc* proposes, on the basis of the work of Neumann, and on the supposition that the osmotic pressure of a totally dissociated normal solution (containing one gramme-molecule in the dissociated state) is equal to 22 atmospheres, a series of this kind, as follows

Electromotive Series of Metals in Solution.

(Value of P at 17° C)

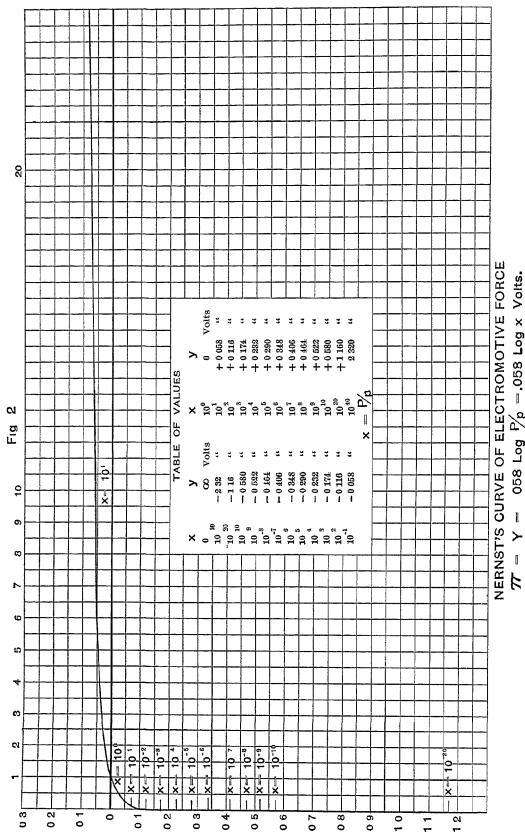
	Atmospheres		Atmospheres
Zinc, . . .	9.9×10^{18}	Lead, . . .	1.1×10^{-3}
Cadmium, . .	2.7×10^6	Hydrogen, . .	9.9×10^{-4}
Thallium, . .	7.7×10^2	Copper, . . .	4.8×10^{-20} (?)
Iron, . . .	1.2×10^4	Mercury, . . .	1.1×10^{-16}
Cobalt, . . .	1.9×10^0	Silver, . . .	2.3×10^{-17}
Nickel, . . .	1.3×10^0	Palladium, . .	1.5×10^{-36}

But it is in the varying number of ions present in solution that the true explanation of the apparent anomalies in the electromotive series was found. According to this theory the position of the metal in the series ought to vary in different solutions in accordance with the number of ions of the given metal that can exist in the given solution

Complex Ions.—The anomalous position of copper, gold and silver in cyanide solutions is here explained for the first time. According to this view, there are very few metallic ions of these metals in solutions of their cyanides. For example, the double cyanide of gold and potassium (potassium auro-cyanide) dissociates, in part, first into a positive ion $K(+)$ † and a nega-

* *Elements of Electrochemistry*, p. 228

† The expression (+) means that the ion after which it is written carries a positive charge of electricity, the expression (—) means that the ion carries a negative charge, and (±) that it is neutral, or not electrified



tive ion AuCy_2 (—). The latter, in accordance with the "mass-law," also dissociates, to a very slight extent, into AuCy (\pm) and Cy (—), and the AuCy , in accordance with the same mass-law, dissociates, to an almost infinitesimal extent, into Au (+) and

Cy(—) The metallic gold ions, thus existing to an almost infinitesimal extent in cyanide solutions, are the only ones that exert an osmotic pressure against the solution-pressure of the gold. Hence, in spite of the low solution-pressure of the gold, the still lower osmotic pressure of the few gold ions present renders the potential of the gold in cyanide solutions remarkably high. Its solubility, also, is thereby explained

But a high potential difference does not necessarily indicate the great solubility of a metal, it may, in fact, indicate the opposite. For instance, the electromotive force of silver in cyanide of potassium solutions is high; but in sulphide of potassium solutions it is still higher—owing, in this case, to the extreme insolubility of the sulphide of silver. This extreme insolubility of the sulphide of silver reduces to a minimum the number of metallic silver ions that are present in the solution, diminishes the osmotic pressure of the ions, and hence increases the electromotive force

The explanation of these remarkable exceptions that “prove the rule,” is due to the work of Ostwald, who, more than any one else, has filled in the gaps and explained away the difficulties presented by the new views

Beyond doubt, the gold, the silver and the copper in the cyanide solution are mainly combined with Cy_2 to form electro-negative ions $\text{AuCy}_2(\text{—})$, $\text{AgCy}_2(\text{—})$, and $\text{CuCy}_2(\text{—})$. As to silver, this conclusion is to be drawn, in fact, from Hittorf's early experiments, and, as to gold and copper, from those of Ostwald, already described.* These ions have been termed by Ostwald “complex ions,” to indicate that they contain the metals in a combination in which their ordinary chemical reactions are entirely masked. There are many other such combinations the thiosulphites of gold and silver, the ferrocyanides and ferricyanides, the platinochlorides, etc., all fail to answer the ordinary tests for the gold, silver, iron, and platinum that they contain. The alkaline sulphhydrates of many of the metals are also examples of the same fact

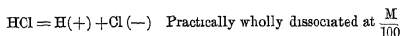
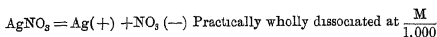
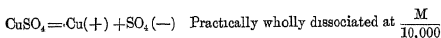
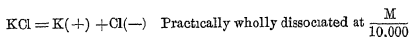
It is for this reason that all of the ordinary reagents fail to precipitate the gold and silver from cyanide solutions. For

* See Christy, “The Solution and Precipitation of the Cyanide of Gold,” *Trans.*, xxvi, 758 et seq

this reason, also, the electric current causes a transfer of the electronegative ion from the negative to the positive pole, or anode, in the opposite direction to that ordinarily taken by the metals, and only the comparatively few electropositive gold ions present in the solution travel towards the cathode or negative electrode of the deposition-box. As already shown in my paper, just cited, this necessarily retards the electrodeposition of the gold from cyanide solutions. However, the potassium ions, on giving up their electric charge to the cathode, precipitate gold from the adjacent solution, and this helps matters out. Nevertheless, the travel of the $\text{AuCy}_2(-)$ ions to the anode considerably retards the precipitation of the gold.

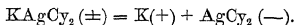
To illustrate the great difference in the osmotic pressure exerted by the complex ions as compared with the ordinary case of dissociation, the following examples are cited from the work of Ostwald and his pupils

Ordinary dissociation is represented by the cases of solutions of potassium chloride, copper sulphate, silver nitrate, and hydrochloric acid. These are found to be dissociated as follows:



The above characteristic cases show that the degree of dissociation varies extremely with different salts, but with many substances, like silver nitrate and hydrochloric acid, is practically complete at very moderate dilutions.

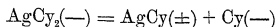
Let us take in contrast the case of a complex ion, that produced, for instance, by the dissociation of potassium argentocyanide. According to an investigation of Morgan,* the dissociation takes place in three steps. Of these, the first is very complete



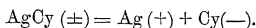
(The latter is the "complex ion.")

* *Zeitsch. für Phys. Chemie*, Bd. xvi, S. 513

The second occurs in very small amount.



The third is in almost infinitesimal traces:



In the case of $\frac{M}{20}$ KAgCy₂, Morgan shows that the first step is almost complete, the second step is $2.76 \times 10^{-3} M = 5$ per cent. dissociated, and the third step shows of Ag(+) ions, $3.65 \times 10^{-11} M = 3.65 \times 108 \times 1000 \times 10^{-11} = 3.94 \times 10^{-6}$ mg. per liter,—that is, there are only about four millionths of a milligramme of silver in the ionic state in a liter of such a solution.

Let us compare this with the dissociation in a $\frac{M}{20}$ AgNO₃ solution. Morgan finds this to be 86.5 per cent. dissociated, hence a liter of such solution will contain $0.865 \times 108 \times \frac{1000}{20} = 4.36 \times 10^3$ mg. of Ag(+) ions per liter.

The ratio of silver ions in the nitrate solution to those in the cyanide solution is therefore

$$\frac{4.36 \times 10^3}{3.94 \times 10^{-6}} = 1.11 \times 10^9.$$

Hence, there are over a billion times as many silver ions in $\frac{M}{20}$ silver nitrate as in silver cyanide.

This makes clear at once the reason of the great difference between the osmotic pressure of the silver ions in the nitrate and in the cyanide solution, and consequently the reason why the electromotive force of silver is so much greater in the cyanide solutions. The case of potassium aurocyanide and other complex salts is entirely similar to that of potassium argentocyanide. It should be further stated that, according to this view, ions can only form or disappear in infinitesimal traces, sufficient to bring about a static equilibrium, unless they appear or disappear in pairs, positive and negative, as they

do in the continuous passage of the current through the electrolytic cell. It is for this reason that it is necessary to have two electrodes to any galvanic cell, one to receive the discharge of electricity from the positively electrified cathions, and the other to receive that from the negatively electrified anions. Without both of these, a continuous current is impossible.

In considering this case of the Daniell cell, for instance: If we represent the solution-pressure of the zinc by P_1 , the osmotic pressure of the zinc ions present in the zinc sulphate by p_1 , and the similar values for the copper by P_2 and for copper ions in the copper sulphate by p_2 , we shall have for the electromotive force of the zinc in zinc sulphate

$$\pi_1 = \frac{0.0575}{2} \log \frac{P_1}{p_1},$$

and for the copper in copper sulphate,

$$\pi_2 = \frac{0.0575}{2} \log \frac{P_2}{p_2}.$$

Either of these alone can give, not a continuous current, but only a static charge of ions, which prevents further action; but when they are combined on a closed circuit, as in the Daniell or gravity-cell, we have a resulting difference of potential.

$$\begin{aligned} \pi = \pi_1 - \pi_2 &= \frac{0.0575}{2} \left(\log \frac{P_1}{p_1} - \log \frac{P_2}{p_2} \right) = \\ &= \frac{0.0575}{2} \log \frac{P_1 \times p_2}{p_1 \times P_2} \end{aligned}$$

On the other hand, in a concentration-cell, with either of these metals (copper electrodes, for instance), one in a strong and the other in a weak solution of copper sulphate, we should have $P_1 = P_2$ in the above formula, and the only difference would be in the differing concentration of the ions p_1 and p_2 in the strong and weak solutions. Making these substitutions in the formula, we should have, in this case

$$\pi = \frac{0.0575}{2} \log \frac{p_2}{p_1}.$$

In this case it is evident that the solution-pressure of the metal itself plays no part in creating the electromotive force of the combination. It is entirely due to the relative number of ions present in the strong and weak solutions. The solution containing the smaller number of ions per unit-volume will oppose to the solution-pressure of the metal immersed in it the smaller resistance, and that metal will dissolve and the other will precipitate.

The above outline gives only in the briefest way a summary of some of the hardest thinking and closest reasoning that has been done of late in one of the most important departments of physical chemistry. It is, perhaps, too much to hope that the conclusions reached are all final. But they rest on such a firm foundation of experimental work, and explain so much that is otherwise inexplicable, that it is certain that they contain a large amount of truth. The details will probably be filled in quite differently from what we now expect, but the great mass seems to be solid gain. The importance of these new views in the study of chemical geology and the deposition of ores, in every branch of the metallurgical art and in all departments of practical chemistry, has hardly begun to be appreciated and utilized. It is not too much to say that ionic action lies at the bottom of all plant- and animal-life, and that the new views are sure to create a revolution in the study of physiological chemistry, biology, pathology and therapeutics. In every department of physical science where they have been applied, they have acted like a new ferment, this speaks volumes for their usefulness and virility.*

Objections to the New Electrolytic Theory—The above theories have not been received without opposition from many chemists and physicists of no little weight. Many of the first opponents to the theory have been overthrown, and point by point has

* Those who are interested in following up these ideas more at length will find the subject treated *in extenso* in Ostwald's *Elektrochemie, ihre Geschichte und Lehre*, Leipzig, 1896 (1150 pp), his *Chemische Energie*, Leipzig, 1893 (1090 pp), and Nernst's *Theoretische Chemie*, Stuttgart, 1893 (580 pp). An admirable summary of these views appears in *The Elements of Electrochemistry*, translated into English by W R Whitney, from the German of Le Blanc, Macmillan & Co., London and New York, 1896 (pp. 282). Since this paper was presented, another excellent work has appeared *Theory of Electrolytic Dissociation*, by H C. Jones, Macmillan & Co., 1900, pp 283.

been won against the strongest opposition. But the field is by no means clear of weighty objectors. The English school, led by Pickering with his "hydrate theory," has opposed most bitterly the new theory of "dissociation." Others, such as Crompton in England, and Bucherer in Germany, have proposed what may be termed the "association" as opposed to the "dissociation" theory. The battle still rages. While the issue seems certain in the main to be in favor of the new views, there is not wanting evidence of the wisdom of a compromise on certain minor but important points.

It will be noticed that the adherents of the dissociation theory neglect *in toto* the effect of the solvent. Formerly, chemists fixed their eyes on the mystic power of the solvent to clear up any doubtful question. The new theorists ignore the solvent entirely. It is indeed astonishing what they have been able to explain without it, but, like Banquo's ghost, "it will not down." They have assumed the solvent to be without action in bringing about dissociation and electrolysis. They have regarded it simply as of the nature of a vacuum into which the ions were free to expand, and everything has been supposed to be due to the pressure of the ions, nothing to the medium.

But already there are signs of reaction. It has been noticed that not all solvents are capable of changing salts into electrolytes. Some are almost without effect in this respect. In other words, not all liquids are capable of becoming vacua into which the ions may evaporate. This fact of itself is enough to show that the nature of the solvent is not without influence on the dissociation.

It was next noticed that most of the solvents which enable electrolysis to take place contain oxygen, and that of these, those possess the power most strongly which contain the most oxygen. Next, it was suggested that in all probability oxygen is quadrivalent rather than bivalent, as usually supposed. The fact that carbon, which is never known to be anything but quadrivalent, combines with oxygen to form carbon monoxide (CO), favors this view. If oxygen be regarded as at least potentially quadrivalent, an explanation is at once found for the well-known variations in the water of crystallization of salts; for Pickering's remarkable series of "hydrates;" and last, but

not least, the idea suggests itself "May not the ions be, not merely a dissociation of the dissolved salt, but an association of the dissociated ions with one or more water molecules?"

It was first supposed that all solvents capable of forming electrolytes contained oxygen. This was disproved by the discovery cited by Ostwald, that liquefied ammonia (NH_3), a non-conductor, becomes a conductor when salts are dissolved in it. This was cited to prove that the ionizing force was not due to the presence of oxygen. But it was pointed out by Bruehl,* that, like oxygen, the nitrogen in NH_3 has two unsatisfied valencies, which are thus capable of acting like it in producing ionization. He predicts that anhydrous HCN when liquefied, as well as PCl_3 and AsCl_3 , will be likely to have similar effects for similar reasons. Nernst† has also called attention to the singular proportionality between the dissociating power of solvents and their dielectric constant. The latter are as follows for certain solvents

Dielectric Constants (Nernst).

Gases,	.	.	1 00
Hydrocarbons,	.	.	1 7 to 2 6
CS_2 ,	.	.	2 6
Ether,	.	.	4 1
Esters,	.	.	6 9
Acetic Acid,	.	.	9.7
Alcohol,	.	.	26 0
Water,	.	.	80 00

This series might almost serve as showing the relative dissociating-power of these substances

Thwing‡ had also called attention to the remarkable difference of the dielectric constants between water and ice, that of water at 0°C being 79.46, and that of ice at -2°C being 3.36 only. He also gives 10.30 as the constant for liquid acetic acid, and 2.79 for solid. In all these cases, the dissociating power increased with the dielectric constant. This points to relations worth following to a conclusion.

It does seem, then, as if the adherents of the dissociation theory had ignored too much the effect of the solvent, and as if the final theory must be enlarged to include it. Why should

* *Z f Phys Ch*, xxvii., 319, (1898) † *Z f Phys Ch*, xiv, 622 (1894)

‡ *Z f Phys Ch*, xiv, 286 (1894)

the action of the solvent be ignored? Its chemical action, it is true, is often slight, but when we take into account the effect (in dilute solutions) of its relatively great mass, does not this explain why dilute solutions are more dissociated than strong ones? In the latter, the cohesion of the solid still maintains, even in solution, a certain effect; but as the mass of the salt diminishes, and that of the solvent increases, the latter makes up by its mass what it lacks in intensity.

If the solvent is without effect, why does not the solution-pressure of the metals cause them to ionize as freely into a vacuum, or into the air? And why should one solvent be effective and not another?

The dissociation-controversy in England waxed particularly warm in the numbers of *Nature* published in 1897 *

One can hardly read this discussion without feeling that, on the whole, the dissociation theory has the better of it. But the associationists, led by Pickering, are not wholly wrong. Pickering cites one experiment that is worth quoting. He says that when a solution of propyl-alcohol in water is placed within a semi-permeable membrane, the water from without passes through the membrane into the interior. This seems to prove that the membrane is pervious to water but not to propyl-alcohol. But, he adds, when the same vessel is immersed in propyl-alcohol the propyl-alcohol passes in through the membrane, but the water cannot get out. This would seem to prove that the membrane was pervious to the propyl-alcohol but not to the water. He considers this a *reductio ad absurdum*. But Whetham points out that the experiment may be interpreted to mean that the membrane is pervious to either water or to propyl-alcohol, but not to their associated molecules or to the solution of one in the other.

Whetham also points out that the assumption that the ions are dissociated from each other does not in any way contradict the assumption that they are severally associated in some, as yet unknown, manner with the solvent.

* *Nature*, vol lv, Dr H E Armstrong, p 78, against, Prof. O J Lodge, p 151, for, W C D Whetham, for, p 152, Spencer Pickering, against, p 223, Lord Rayleigh, p 253, for, Lord Kelvin, p 273, agnostic, if not wholly skeptical, Prof J. Willard Gibbs, p 461, for, answers some of Lord Kelvin's objections, W C D Whetham, p 606, for, answers Pickering. The discussion is continued in *Nature*, vol lvi, p 29

Lord Kelvin (*loc. cit.*, p. 273) takes an agnostic, if not skeptical, position. After stating the problem of osmotic pressure, he says

"No molecular theory can, for sugar or common salt or alcohol dissolved in water, tell us what is the true osmotic pressure against a membrane permeable to water only, without taking into account laws, quite unknown to us at present, regarding the three sets of mutual attractions or repulsions (1) between the molecules of dissolved substance, (2) between the molecules of the water, (3) between the molecules of the dissolved substance and the molecules of the water"

He follows this with a warning against undue haste in accepting theoretical views as settled while they are still open to debate.

On p 461 (*loc. cit.*) Prof J. Willard Gibbs shows that in the case cited by Lord Kelvin, for dilute solutions, where the relation of the density and pressure of the dissolved substance becomes like that of a gas, it is only necessary to have a single numerical constant in addition to the relation between the density and the osmotic pressure to solve the problem.

It must be remembered that the greatest triumphs of the new theory are confined to dilute solutions, but a complete theory of solutions must, of course, include all states from the dilute solution through the saturated solution to the solid substance with its various hydrates.

In describing the condition of affairs assumed in the new theory of ionic dissociation, Le Blanc says *

"The parts resulting from the dissociation (the ions) are electrically charged, and contain equivalent amounts of positive and negative electricity. It is natural to ask: Whence come these sudden changes of electricity? They seem to be produced from nothing. An answer that seems satisfactory is not difficult to give. It is known that metallic potassium and iodine combine to form potassium iodide. In this combination heat is generated, which shows that the two have entered into a state in which they contain less energy than before. A certain amount of chemical energy doubtless still remains in the compound, and when the salt is dissolved in water, the greater part of this chemical energy is changed into electrical, *through the influence of the solvent*.† This is the energy seated in the charges of the ions. The potassium ion is positively, and the iodine negatively electric. By the aid of the electric current, it is possible to add to these ions the energy in the form of electricity necessary to give them the energy they originally possessed as elements. In such a case, they separate in the ordinary molecular forms at the electrodes."

* Le Blanc, *Elements of Electrochemistry*, p. 60.

† The italics are mine —S B C

It will be noticed that in this explanation of the mode of formation of the ions on the dissociation hypothesis, Le Blanc uses the phrase "*through the influence of the solvent.*" That is, he seems to recognize the need of bringing this influence into the problem. He does not attempt to show how it acts. But if it is able to alter such strong affinities as those of potassium and chlorine, or even of potassium and iodine, by changing the chemical into electric energy, such action is surely worth studying most closely.

I am firmly convinced that the next great advance will be made when the effect of the solvent is more closely studied. But while believing that the association or loose combination of the water-molecules with the dissociated ions plays an important, though as yet unknown, part in electrolysis, I shall, in what follows, continue to use the method of nomenclature already in use for the ions, in the absence of a better system.*

II—METHODS USED IN THIS INVESTIGATION.

In looking about for some means of determining the relative affinities of the metals for cyanide solutions, I long ago came to the conclusion that the determination of the relative electromotive forces of the metals in solutions of different strengths was the simplest, readiest, and most certain that could be selected. For, properly considered, it shows the actual tendency of the metal to go into solution. My first experiments were made in this direction in August, 1896. I made at that time a large number of preliminary determinations, the results of which were presented in a lecture given February 1, 1897, before the California Academy of Sciences, in San Francisco. At that time, the curves shown in Fig. 5 were projected on the screen by a stereopticon before an audience of 300 persons.

* H C Jones, *Z f Phys Ch.*, xiv., 346, gives some interesting determinations of the EMF of the combination Ag, AgNO₃ Aq, AgNO₃, ethyl-alcohol, Ag, which seem to show that the solution-pressure P may not be a constant for a given temperature, but may also be a function of the solvent.

See also J J Thomson, *Phil. Mag.*, Fifth Series, xxxvi., 320 (1893), on the action of the dielectric in bringing about dissociation by its inductive influence

For other attempts to explain the influence of the solvent, see Biedig, *Z f Phys. Ch.*, iv., 444 (1889), "Kinetic Nature of Osmotic Pressure," also Noyes, *Id.*, v., 53 (1890), and Kistiakowsky, *Id.*, vi., 115 (1890), "Specific Attractions in Salt Solutions"

The results of these experiments have filled me with constant surprise, when I have noticed what apparently slight causes were capable of making great changes in the electromotive force of the same metal. The great delicacy of the method proved to be the chief source of difficulty in its application, while at the same time it reported faithfully the facts as they exist in nature.

Two methods have been used in these determinations, the first being what I have, for brevity, called the "Deflection" method, and the other the "Compensation" or "Zero" method of Poggendorf.

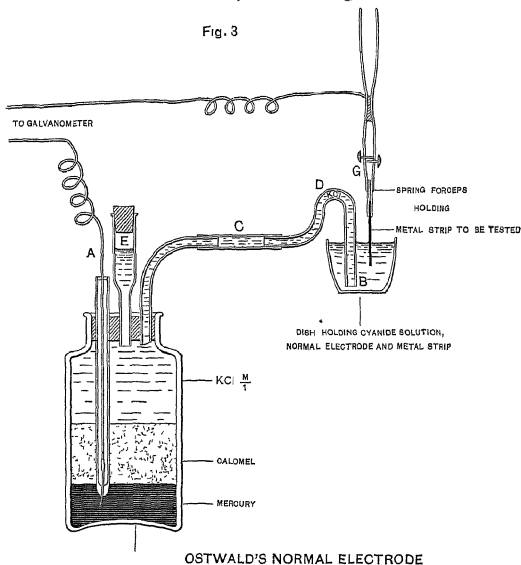
In each case an electrolytic cell is constructed with two electrodes, each immersed in a separate solution. One, consisting of the metal to be tested, was held in the points of a platinum-tipped pair of forceps, electrically connected with a galvanometer, and was immersed in a vessel containing the cyanide solution of the given strength. The other was in all cases the "normal" electrode of Prof Ostwald, consisting of mercury, electrically connected with the galvanometer by means of a glass-coated platinum wire. The surface of the mercury is covered with a layer of mercurous chloride, a couple of inches thick, and a solution of chloride of potassium of one gramme-molecule $\frac{M}{1}$ (in this case also a normal solution).

The two vessels containing the electrodes are connected, as shown in Fig 3, by means of the tube C and the siphon D, the latter being filled with $\frac{M}{1}$ KCl solution, like that in the normal electrode. I have added a small tube E, ordinarily closed with a cork, for the purpose of displacing at intervals the solution in the siphon D with fresh KCl solution, to avoid the diffusion of the cyanide solution through the latter back into the normal electrode. For the same reason the position of the normal electrode is ordinarily a little higher than that shown in the figure, so that any accidental action of the siphon shall be rather away from the normal electrode than into it.

The purpose of the normal electrode of Ostwald is to have a non-polarizable electrode in a solution of known strength and electromotive force. This is fixed at -0.560 volts. That is, in the case of the normal electrode, the quicksilver ions tend to

precipitate themselves on the surface of the mercury, and the solution is therefore negative to the metal by 0.560 volts. That is, the positive current tends to flow through the solution to the mercury, which becomes positively electrified, while the solution itself becomes negatively electrified.

Now, if we neglect the slight electromotive force due to the contact of the two solutions, the resulting electromotive force

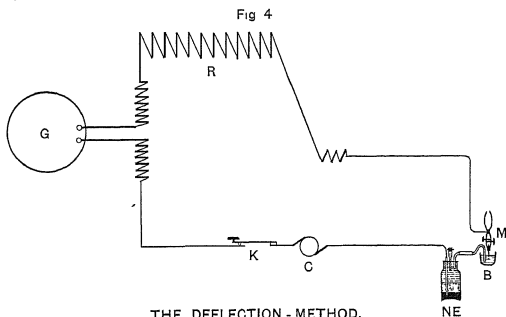


of the combined cell is the algebraic sum of the electromotive forces active at the two electrodes. Hence, if we subtract 0.560 from the EMF of the cell, we have the EMF of the metal under consideration. The algebraic sign indicates the direction of the positive current.

The Deflection Method—This method is much the most convenient for such investigations, particularly in the first roughing-out of a large amount of material. With proper precau-

tions, it gives results not less reliable than those of the zero method; and it has the great advantage over the latter that the rapid changes of electromotive force may be followed almost as they occur.

The method is illustrated in Fig. 4. B is the cell containing the cyanide solution and the metal M to be tested; NE is Ostwald's normal electrode, R is a resistance which varied in the tests from 30,000 to 200,000 ohms; G is a Wiedemann reflecting galvanometer; K, a make-and break-circuit key; and C, a commutator.



- | | |
|--------------------------------------|---|
| B, Cell Containing Cyanide Solution, | R, Resistance of from 30,000 to 200,000 Ohms, |
| M, Metal to be Tested, | G, Wiedemann's Reflecting Galvanometer, |
| NE, Ostwald's Normal Electrode, | K, Make - and Break - Circuit Key |

The galvanometer was calibrated by replacing the cells B and NE with a Latimer-Clark cell, prepared according to the directions of Ostwald, and noting the deflection produced by its voltage through the given resistance of 30,000 to 200,000 ohms. The voltage was taken as $EMF = 1.438 - 0.001 \times (t^\circ - 15^\circ \text{ C.})$ volts.

Most of the concentrations of potassium cyanide were $\frac{M}{1}$ (one gramme-molecule, 65 grammes per liter, or 6.5 per cent), or fractional multiples of this in tenths. Thus the series used was frequently $\frac{M}{1}, \frac{M}{10}, \frac{M}{100}, \frac{M}{1000}, \frac{M}{10,000}, \frac{M}{100,000}, \frac{M}{1,000,000}$.

As there is no little difference in the methods of notation in

use, and much resulting confusion, the following methods of notation will always be used in this paper. We shall follow the motion of the positive ions through the solution, and the mode of notation will depend entirely on that. When the motion of the positive ion *in the solution* is from the metal to the solution, the metal is said to be electropositive, because it gives up positive ions to the solution and causes the solution to become positively electrified, itself becoming at the same time negatively electrified. Such, for instance, is the case of zinc in a solution of zinc sulphate. When, on the other hand, the solution gives up positive ions to the metal immersed in it, as is the case with copper in a solution of copper sulphate, the metal is said to be electronegative, for it causes the solution in which it is immersed to become electronegative, itself, at the same time, becoming positively electrified. The quicksilver in Ostwald's normal electrode is another example. The + or — sign, then, here indicates the direction of ionic motion, and simply shows whether the given positive ions tend to flow away from the metal into the solution or towards the metal from the solution. That is, whether the "solution-pressure" of the metal is greater or less than the "osmotic pressure" of the ions in solution.*

Now, when an electropositive and an electronegative metal are coupled, the direction of flow of the ions of both through the solution is the same, and the electromotive force of the combination is the arithmetical sum of those of the ingredients. When two electropositive or two electronegative metals are coupled, the ions tend to flow through the solution in opposite directions; hence, the electromotive force of the combination is equal to the arithmetical difference between the separate electromotive forces, the direction of motion, and hence the sign, being that of the greater.

In combinations in which the Ostwald normal electrode is one member, we know the amount and direction of one electromotive force, and hence, when we measure that of the combination, it is easy to calculate that of the other (neglecting the slight electromotive force due to the contact of the solutions).†

* With regard to the anions, the + and — signs have an inverse meaning

† This, except in cases of great differences in the concentration of the solutions, has been shown to cause an error of only a few thousandths or hundredths of a volt

Thus, if, against the normal electrode, aluminum in a $\frac{M}{I}$ solution of KCy gives an EMF = + 1.55 volts,—that is, if the current flows from the aluminum to the mercury, the same as in the case of mercury,—it follows that the EMF of the aluminum in $\frac{M}{I}$ KCy will be $+1.55 - 0.560 = +0.99$ volts.

Again, if a strip of amalgamated zinc under similar circumstances gives a voltage of + 1.49 volts, the EMF of amalgamated zinc in a $\frac{M}{I}$ KCy solution will be $+1.49 - 0.560 = +0.93$ volts.

In making the determinations, it must be evident from the formula that, if there are few ions of the given metal present in the solution at the start, the introduction of a very few more will make great changes in the value of the EMF.

For in $\log \frac{P}{p}$ it must be evident that, as P is constant (for a given temperature), the value will depend entirely on p , and the smaller p is, the greater will be the effect due to slight changes in p . Hence, it will be impossible to get constant values for the EMF, unless the value of p is nearly constant, that is, when the solution is saturated with ions at the given temperature. That is the case with the normal electrode, where the mercury lies in a saturated solution of mercurous chloride. The mercury is thus in equilibrium with its ions, and a constant EMF results.

To get perfectly constant results with cyanide solutions, it would be necessary to have the solution saturated with the cyanide of the metal in question. But while this would give us a very satisfactory electromotive series, it would not give us a measure of the action of the unsaturated cyanide solution, just as it acts on the ores. We must, therefore, be content with results that are not entirely concordant, and take the best of a large number of determinations.

The strips used were always freshly burnished with sand-paper, cooled, and touched to a grounded platinum wire to discharge any electricity with which they might have been charged in burnishing.

Preliminary Results with the Deflection Method—The following preliminary results were obtained in October to December, 1896,

TABLE I.—*Electromotive Force of Metals in Cyanide Solutions.*
Deflection Method. Preliminary Experiments.
October–December, 1896.

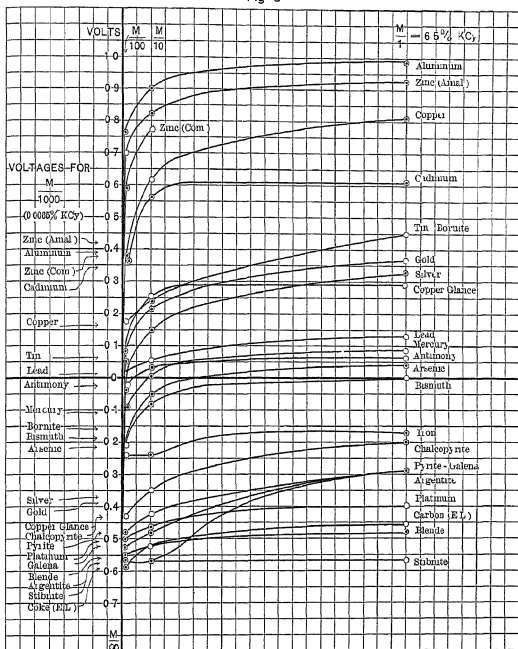
	Ostwald's Normal Electrode — 0.560 Volts			
	$\frac{M}{1}$ KCy	$\frac{M}{10}$ KCy	$\frac{M}{100}$ KCy	
	Volts	Volts	Volts	
*Aluminum . . .	+0.99	+0.90	+0.76	+0.40
*Zinc, amalgamated	+0.93	+0.82	+0.70	+0.44
*Zinc, commercial	Not determ	+0.77	+0.59	+0.39
*Copper . . .	+0.81	+0.62	+0.37	+0.16
*Cadmium . . .	+0.61	+0.57	+0.35	....
Cadmium, amalgamated	+0.55	+0.31	+0.19	
*Tin	+0.45	+0.24	+0.17	+0.06
*Bornite	+0.45	+0.25	—0.16	..
Copper, amalgamated	+0.39 (?)	+0.41	—0.14 (?)	—0.12 (?)
*Gold	+0.37	+0.23	+0.09	—0.38
*Silver	+0.33	+0.15	—0.05	—0.36
*Copper-Glance	+0.29 (?)	+0.25	+0.05	—0.44
*Lead	+0.13	+0.05	+0.01	
Tin, amalgamated	Not determ	+0.01	—0.07	—0.12
Lead, amalgamated	Not determ		—0.03	.
*Quicksilver . .	—0.09	+0.01	—0.11	..
Gold, amalgamated	.	..	—0.13	—0.26
*Antimony . . .	+0.06	+0.03	—0.03	.
*Arsenic	+0.04	—0.05	—0.21	
*Bismuth	+0.00	—0.06	—0.20	....
Niccolite	—0.11	—0.17	—0.44	....
*Iron	—0.17	—0.24	—0.24	.
*Chalcopyrite . .	—0.20	—0.34	—0.44	.
*Pyrite	—0.28	—0.42	—0.48	..
*Galena	—0.28	—0.48	—0.52	.
*Argentite	—0.28	—0.56	—0.55 (?)	..
Berthierite	—0.30	—0.52	—0.52	..
Speisscobalt . . .	—0.30	—0.33	—0.50	
Magnetopyrite . .	—0.30	—0.40	—0.54	
Fahlre	—0.36	—0.52	—0.52	..
Arsenopyrite . . .	—0.40	—0.45	—0.54	
*Platinum	—0.40	—0.46	—0.50	
Cuprite	—0.43	—0.55	—0.57	
*Electric Light Carbon	—0.46	—0.52 (?)	—0.57	.
*Blende	—0.48	—0.52	—0.55	..
Boulangerite . . .	—0.50	—0.55	—0.55	
Bournonite	—0.50	—0.55	—0.56	..
Coke	—0.52	—0.52	—0.42 (?)	
Ruby Silver-Ore . .	—0.54	—0.53 (?)	—0.54	
Stephanite	—0.54	—0.55	—0.52 (?)	.
*Stibnite	—0.56	—0.56	—0.56	.

with some of the common metals and minerals. The metals were good commercial articles, such as are in use in the arts, except in the case of gold, silver and quicksilver, which were chemically pure. In the case of some of the minerals, such as zincblende, stibnite, etc., the electrical resistance was probably

so high in comparison with that of the intercalated resistance that the results may be somewhat low.

Nevertheless, they give at once some important relations

Fig 5



PRELIMINARY RESULTS. OCT - DEC 1896.

which must exist whenever the cyanide process is applied in the treatment of ores.

The electromotive forces of the metals and minerals marked with an asterisk in the above table have been plotted in Fig. 5. The Y axis shows the potential in volts, the X axis the concentration in gramme-molecules and also in percentage of KCy.

It will be noticed that in most cases the curves approximate quite closely to the logarithmic curve which theory would give (see Fig. 2), supposing the osmotic pressure of the metallic ions present to be inversely proportional to the concentration of the free potassium cyanide present, but they have different origins.

It will be noticed that the electromotive force of commercial sheet-zinc is increased by amalgamation, probably by reducing local action with some of its impurities, by which some of the current produced is short-circuited. In all the other experiments, amalgamation reduces the electromotive force of the combination.

With some substances, particularly aluminum, copper, iron, platinum and gas-carbon, it was very difficult to get concordant results, with aluminum and copper this seemed to be due to a tendency to form an insoluble film on the surface of the metal, which put a stop to further action. With copper and iron it was also possibly due to a tendency of the metals to a change of valency, which is accompanied by a change in the electrical state. With platinum and gas-carbon, it was not improbably due to a varying content of absorbed gas.

In testing the minerals, it was in all cases difficult to get a complete electrical contact between the tips of the platinum forceps and the rough surface of the mineral fragment, so that the results are only provisional, particularly as the resistance in some of these cases was very high. Nevertheless, the results are very interesting. They show, for instance, that not all copper minerals have a strong action on the current. Pure chalcopyrite, for instance, has hardly more action than pure pyrite, while bornite and copper-glance have a very decided tendency to go into solution. Cuprite is also apparently very little acted on, though this may be due to its high resistance rather than to a lack of tendency to dissolve. The soluble salts and minerals of copper could not be tested in this manner, owing to their non-conductivity.

It is plain, however, that pure chalcopyrite, galena, argentite, magnetopyrite, fahlore, arsenopyrite, blende, boulangerite, bournonite, ruby silver-ore, stephanite and stibnite, when free from their oxidation-products, are apparently very little acted on by cyanide solutions.

It is also plain that a particle of metallic gold, in contact with

a particle of pyrite, forms a galvanic couple in $\frac{M}{1}$ or 6.5 per cent KCy solution, equal to + 0.65 volts in $\frac{M}{10}$ or 0.65 per cent. KCy solution, + 0.65 volts, and in $\frac{M}{100}$ or 0.65 per cent. KCy solution, + 0.57 volts. With zinc under the same circumstances (if we take for the $\frac{M}{1}$ KCy solution the figures for amalgamated zinc), taking the zinc as the more electropositive metal, and subtracting the potential of gold, we have differences of + 0.56 volts, + 0.54 volts, and + 0.50 volts. In short, these figures would measure the tendency of the zinc to dissolve, or of the gold to precipitate in KCy solutions of these strengths.

According to these figures, the precipitating power of the zinc seems to hold up quite well for the dilute solutions. The actual failure to precipitate the gold, sometimes met with in dilute solutions, is no doubt due to films of cyanide or hydrate of zinc, which form incrustations on the surface of the zinc and thus prevent contact. The fact that the use of a small amount of fresh cyanide or of caustic potash in the zinc-boxes starts precipitation again, seems to favor this explanation.

The Zero-Method.—This method is shown in outline in Fig 6. NE is the Ostwald normal electrode. B is the cell containing the cyanide solution in which, as before, is immersed the metal M to be tested. At G is a galvanometer. At R is a resistance, graduated, in my experiments, into 10,000 parts. A storage-battery of two volts and the combination-cell NE-B are so connected that their positive poles are both connected at the same end of the resistance R. The negative pole of the storage-battery is attached to the other end of the resistance R, so that the whole current of the storage-battery discharges constantly through R. The latter should be great enough to avoid heating, and to maintain a constant potential between the ends of R. The other terminal of the combination (the negative pole) is then moved along the resistance R till some distance, a , is reached at which the EMF force of NE-B is exactly balanced by the EMF force of the storage-battery for that fraction of R represented by a . In this case there is no deflection of the galvanometer, at other points the galvanometer will be

deflected either to the right or left, according as too much or too little EMF is used to balance NE-B. The EMF of the storage-battery, is, of course, first calibrated by comparing it with a standard Latimer-Clark cell, placed where NE-B is

This method of determining the EMF of a cell is deservedly considered one of the most reliable. With non-polarizing cells, it certainly leaves nothing to be desired. But, in investigations of this kind with cells that are easily polarized, accurate results are obtained only by a long number of very tedious approximations, which render the work almost interminable. For it is, of course, impossible to hit the right balance at first, and, if the connection is made at any point except the right one, the

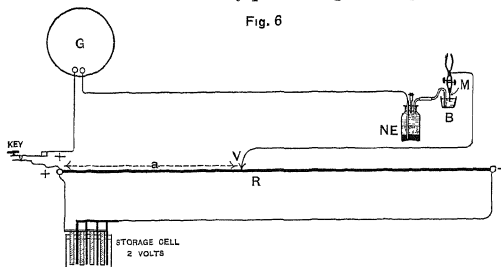


Fig. 6

POGGENDORF'S COMPENSATION - METHOD.

- | | |
|--------------------------------------|--|
| B, Cell Containing Cyanide Solution, | R, Resistance Graduated into 10,000 Parts, |
| M, Metal to be Tested, | V, Movable Contact, |
| NE, Ostwald's Normal Electrode, | G, Wiedemann's Reflecting Galvanometer |

metallic electrode will receive either a positive or negative charge from the storage-battery, and a true reading will be thus made impossible. It is necessary to change the entire solution in B, put in new electrodes at M, drive out the diffused cyanide solution from NE, and so on, till these operations have been repeated perhaps a dozen times. If this is not done, the results are very unreliable. With the deflection method, on the other hand, the observations may be made very rapidly, and though there is a tendency for the readings to be a little low unless they are quickly made, still, with a high intercalated resistance, and a delicate reflecting galvanometer, this method seems to be reliable for these quickly polarizing electrodes.

As I have already stated, and as was first pointed out by Ost-

wald, strictly concordant results are possible only when the electrode is surrounded with a medium already saturated with its ions.

I had intended to verify the results in Table I. with the zero method before publication, but although I had all the apparatus set up for over two years, ready to begin at any time, I was prevented by the constant pressure of routine-work from touching it, till shortly before the time set for the San Francisco meeting of the Institute, in September, 1899. Meantime Prof. A. von Oettingen, professor of physics in the University of Leipzig, read a very valuable paper on this subject before the Chemical and Metallurgical Society of South Africa, in January and February, 1899. In this paper he gives the results of a large number of determinations which he made of the electromotive force of metals in cyanide solutions by means of Pogendorff's compensation method, or, as I shall call it for brevity, the zero method

Professor von Oettingen's results are given in Table II

TABLE II.—*Potentials of Different Metals in Contact with KCy Solutions, at 25° C*

Experiments of Prof A von Oettingen, *Jour. Chem and Metallurgical Soc S Africa*, January and February, 1899

	$\frac{M}{1} \text{ KCy}$	$\frac{M}{10} \text{ KCy}$	$\frac{M}{100} \text{ KCy}$	$\frac{M}{1000} \text{ KCy}$	$\frac{M}{100} \text{ KCy} + \frac{M}{670} \text{ Au}$
	Volts	Volts	Volts	Volts	Volts
Au	{ +0 340 to +0 306	{ +0 180 to +0 218	{ -0 082 to -0 056	{ -0 414 to -0 474	-0 020 to -0 170
Ag	{ +0 330 to +0 314	+0 176 const	-0 020 const	{ -0 340 to -0 200	-0 308 to -0 330
Cu	{ +0 890 to +0 924	{ -0 680 to +0 648	{ -0 212* to +0 380	{ -0 550 to -0 230	
Hg	{ +0 162 to +0 200	{ +0 008 to +0 024	+0 056 const		
Ni	{ -0 290 to +0 194	{ -0 466 to -0 392	{ -0 550 to -0 488	-0 560	
Co	{ +0 182 to -0 196	{ +0 118 to -0 220†	{ -0 168 to -0 240		
Fe	{ -0 056 to -0 146	{ +0 084 to -0 012	{ -0 054 to +0 022	{ -0 008 to +0 050	
Fe ₂ O ₃	{ -0 674 to +0 700	{ -0 796 to -0 720	{ -0 824 to -0 750		
PbO ₂	+0 160 const	+0 110 to +0 118	{ -0 062 to +0 070	-0 006 const	
Pb	+0 164 const	+0 128 const	+0 120 const	+0 120 const	+0 126 const
Zn	{ +0 924 const +0 940	{ +0 730 to +0 800	{ +0 560 to +0 604	+0 480 const	

* On moving the fluid the potential suddenly rises

† The potential changed suddenly from -0 121 to +0 118, then remained constant

(Note the discrepancy between -0 220 in the table and -0 121 in the footnote)

The above results were all obtained by the Poggendorff compensation or zero method, the Lippman capillary electrometer being used as an indicator instead of a galvanometer

Prof. von Oettingen says of these results

"The two figures in each column refer to the first and last observations on each metal, the intermediate values being omitted. The time occupied by the change is very variable, Cu, for instance, took an hour. When no changes occur, this is indicated by a constant. The changes of potential are not always in the same direction, sometimes decreasing, sometimes increasing. But the direction of the changes in any given metal is always the same."

It will be noticed on examining the table that this last sentence is not correct (unless there should be a typographical error in his table). For gold, silver, copper, cobalt, ferric oxide and lead peroxide, the highest value for the same metal is sometimes the first and sometimes the second value. In the case of copper in $\frac{M}{100}$ KCy the results jump from -0.212 volts to $+0.380$ volts—a difference of 0.592 volts. I shall speak of the probable cause of these differences later.*

* There are some other potential differences given by Prof. von Oettingen which I include here

$\frac{\text{Hg}}{\text{Hg}_2\text{SO}_4} = -0.99$	volts	(Ostwald),	$\frac{M}{1}$	Solutions	
$\frac{\text{Zn}}{\text{ZnSO}_4} = +0.524$	"	"	"	"	
$\frac{\text{Mg}}{\text{MgSO}_4} = +1.243$	"	"	"	"	18° C
$\frac{\text{Cd}}{\text{CdSO}_4} = +0.158$	"	"	"	"	"
$\frac{\text{Pb}}{\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2} = -0.089$	"	"	"	"	"
$\frac{\text{Cu}}{\text{CuSO}_4} = -0.582$	volts	"	"	"	"
$\frac{\text{Ag}}{\text{Ag}_2\text{SO}_4} = -1.024$	"	"	"	"	"
$\frac{\text{Hg}}{\text{Hg}_2\text{Cl}_2} = -0.560$	(Ostwald's normal electrode)				

Prof. von Oettingen himself determined the following also (all at 25° C.)

$\frac{\text{Au}}{\text{AuCl}(\text{conc})} = -1.64$	to	1.42	volts, variable
$\frac{\text{Au}}{\frac{M}{1}\text{AuCl}_3} = -1.134$	volts		
$\frac{\text{Au}}{\text{Aqua Regia}} = -1.09$	volts		

In order to make more clear the meaning of Prof. von Oettingen's results, I have plotted them in Fig. 7 as mine are plotted in Fig. 5. In the figures, x is made to mark the molecular concentration $\frac{M}{1}, \frac{M}{10}, \frac{M}{100}, \frac{M}{1000}$, the y axis shows the potential in volts. The designation Zinc 1 means that this was the first value obtained with zinc, the designation Zinc 2, the final value, etc. It will be noticed that sometimes the first value is higher than the second and sometimes *vice versa*, but the results are not consistent throughout, sometimes crossing each other.

The first curves of each metal, except mercury, approximately follow the logarithmic law (on the assumption that the number of metal ions is inversely proportional to the potassium cyanide concentration). Evidently the curves will cross the X axis at different points, and not usually at a molecular concentration $M = 1$, unless it should accidentally happen that $\frac{P}{p} = 1$ for $M = 1$. The second curves of zinc, copper, gold and silver, also approximately follow it. But the second curves of mercury, cobalt, nickel and iron depart considerably from it. It is possible that these departures are due to polarization effects, as already explained. The irregularities are much more marked than with the deflection-method. With that method, provided a sufficiently large resistance is used, the first deflection is the greatest, and is taken as the reading nearest to the truth. The deflection then gradually falls (often quite rapidly, if there is a formation of gas on the face of the electrode); but the electromotive force never rises unless the first effect of the current is to produce a film of gas or insoluble

$$\frac{\text{Au}}{\text{KCyS (sat)}} = -0.26 \text{ to } +0.03, \text{ very variable}$$

$$\frac{\text{Au}}{\text{K}_2\text{S}_7} = +0.21 \text{ volts}$$

$$\frac{\text{M}}{1} \text{ KCyS} = -0.36, \text{ variable volts}$$

$$\frac{\text{Au}}{\text{Na}_2\text{S}} = 0 \text{ to } 0.136 \text{ volts.}$$

$$\frac{\text{Au}}{\frac{\text{M}}{10} \text{ KCyS}} = -0.40 \text{ volts}$$

$$\frac{\text{Ag}}{\text{KCy (sat)}} = +0.536 \text{ volts}$$

$$\frac{\text{Au}}{\text{KCy (sat.)}} = +0.50 \text{ volts}$$

$$\frac{\text{Cu}}{\text{KCy (sat)}} = +1.154 \text{ volts}$$

$$\frac{\text{Au}}{\text{K}_2\text{S}} = +0.14 \text{ volts}$$

$$\frac{\text{Zn}}{\text{KCy (sat.)}} = +1.196 \text{ volts}$$

results hitherto used, while it shows very well the near approach of the curve to the true logarithmic curve, has the disadvantage that only three or four values for the tenth ratio can be plotted. If, however, instead of making $x = \frac{P}{p}$, as we have done, we let $x = \log \frac{P}{p}$, and plot the curve $y = 0.058 \log. \frac{P}{p}$ volts, the curve becomes a straight line passing through the origin at 0. For $x = 0$, $y = 0$.

This curve is plotted in Fig. 8 for values of $x = \log. \frac{P}{p}$ from + 13 to - 12, which gives voltages from + 0.755 to - 0.696, and the table shows values from $x = \log. \frac{P}{p} =$ minus infinity to 40. It shows what an enormous change in the value $\frac{P}{p}$ is necessary to produce a very moderate change in the voltage. Thus, to produce a change of 2.32 volts, a change in the ratio $\frac{P}{p} = 10^{40}$ (or ten to the fortieth power) is necessary.

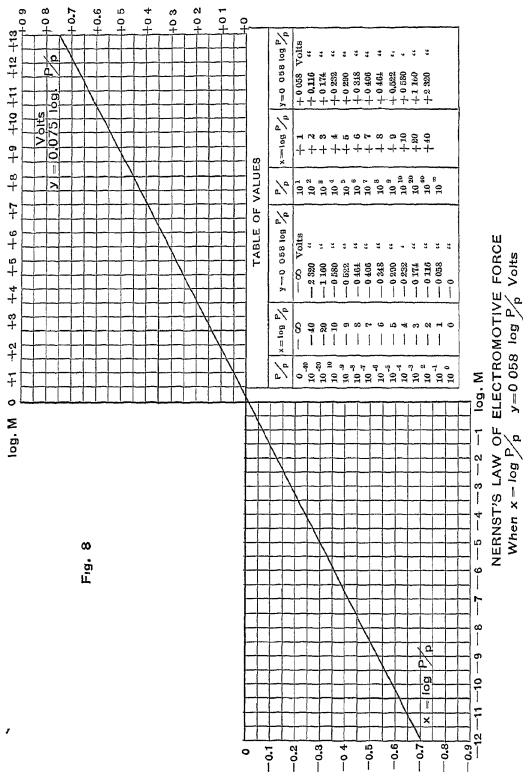
In our experiments, of course, we do not know the value of $\frac{P}{p}$, but as a first approximation we may assume it inversely proportional to the molecular concentration $M \times 10^n$.

On the axis of x is plotted the logarithm of the molecular concentration expressed in the powers of 10. Thus, $x = \log M = \log. 10^{\pm n}$. The y axis gives the EMF in volts. For comparison the theoretic formula of Nernst is also given.

If we plot Prof. von Oettingen's results, as in Fig. 9, on this plan, they become at once more intelligible. We see at once that all the curves do not remain straight lines. The zinc follows along very nearly in the theoretic straight line. The copper starts well, but soon falls quite rapidly, due probably to increasing dissociations. The gold and silver approximate fairly well, also, but the rest depart from it considerably.

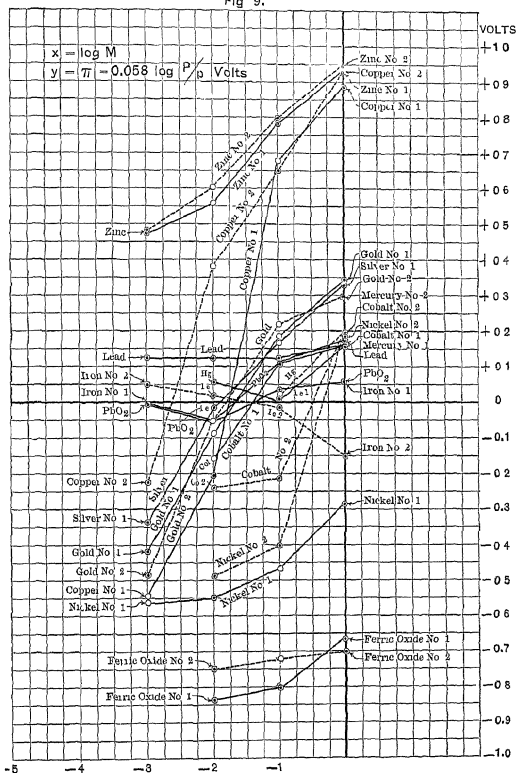
Comparison of the Deflection and Zero Methods.—Since the results of Prof. von Oettingen were published, I have thought best to try the zero method as well as the deflection method, and to compare the results so far obtained with each other. I have also decided to plot the results by the same method as

shown in Fig. 8, as it enables us to compare the results over a wider range of dilution than the former method of tabulation would cover.



After the foregoing description and discussion of the various methods employed in this investigation, the reader will be able

Fig 9.



E.M.F. OF METALS IN CYANIDE-SOLUTIONS.

Prof v Oettingen of Leipzig (J Chem and Met Soc S A. Feb 1897)

On the horizontal (x) axis are laid off the values of $\log M = \log 10^p$, on the vertical (y) axis, the actual volts

to study intelligently the tabulated results of the tests herein-after stated.

III.—RESULTS OF EXPERIMENTS.

The following tables show, for the several metals tested, my own results, obtained at different times and by different methods, as well as those of Prof. von Oettingen. In every case, each observation was made independently, without regard to the ultimate result of its reduction. But the later readings are more reliable than the earlier, because a certain knack in catching the needle at its maximum position, before the voltage begins to fall, was acquired during the work. The tables give the readings as reduced from the actual observations, without attempted correction; but when any anomaly rendered the observation uncertain, this is indicated by a (?). Such was the case particularly in the readings with distilled water (M divided by ∞), which were very uncertain, especially for easily oxidizable metals like zinc and iron

TABLE III.—*Electromotive Force of Zinc (Commercial Sheet, Burnished) in KCy*

Curve	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Note-book B1 page	67	176	177	186	193	Publish'd	Publish'd
Date	Oct 19, '96	A'g 30, '99	A'g 30, '99	Sep 4, '99	Sep 8, '99	Feb, '99	Feb, '99
Method	Deflect †	Zero †	Deflect †	Deflect †	Deflect	Zero	Zero
Resis ohms	100,000	100,000	100,000	100,000	200,000		
Temperature	22° C	19° C	19° C	19° C	198 C	25° C	25° C
Observer	Christy	Christy	Christy	Christy	Christy	Von Oettingen	Von Oettingen
EMF (N E = -0.560)	Volts	Volts	Volts	Volts	Volts	Volts	Volts
Concentration							
KCy $\frac{M}{1}$		+0.946		+0.906	+0.914‡	+0.924	+0.940
$\frac{M}{10}$	+0.770	+0.861		+0.815	+0.836‡	+0.780	+0.800
$\frac{M}{100}$	+0.585	+0.772		+0.780	+0.735‡	+0.560	+0.604
$\frac{M}{1000}$	+0.385	+0.415	+0.386	+0.300	+0.371||	+0.450	+0.480
$\frac{M}{10,000}$..		+0.385 (?)	+0.326	+0.270	+0.332		
$\frac{M}{100,000}$		+0.355	+0.320	+0.270 (?)	+0.332 (?)		
$\frac{M}{1,000,000}$..		+0.383 (?)	+0.312	+0.282 (?)	+0.332 (?)		
$\frac{M}{\infty}$ (= H ₂ O)	+0.041 (?)	+0.372 (?)	+0.256 (?)	+0.240 (?)	+0.293 (?)		
				+0.350 (?)			

* Used same strip of zinc throughout experiments, burnishing each time Tested from strong to weak solutions † Used new burnished strip each time

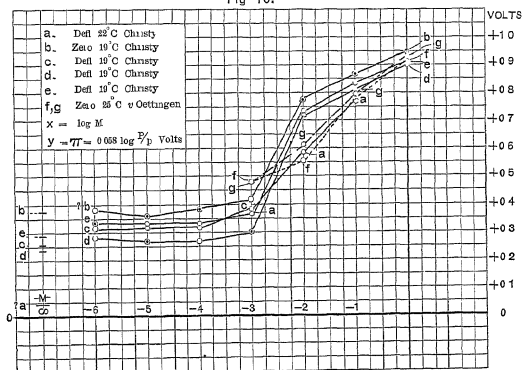
‡ Same strip, burnished each time Tested from weak to strong solutions.

§ Fine bubbles form on zinc and then voltage falls Shaking causes bubbles to escape, and voltage rises || Below this, no gas-bubbles visible to naked eye, but voltage falls, and then rises on shaking

Experiments with Commercial Sheet-Zinc.—Experiments were made at different times, with both the zero and the deflection method, on the ordinary commercial sheet-zinc, such as is actually used in making zinc-shavings for precipitating gold. The results are given in Table III., and those of Prof. von Oettingen have been introduced into the same table, for comparison.

These results are plotted together for comparison in Fig. 10. It will be evident that from $\frac{M}{1}$ to $\frac{M}{100}$, or from 6.5 to 0.065 per

Fig 10.



E.M.F. OF ZINC IN KCy. SOLS.

On the horizontal (x) axis are laid off the values of $\log M = \log 10^x$; on the vertical (y) axis, the actual volts

cent., the curve nearly follows the theoretic straight line.

Curves *a*, *f* and *g* appear to follow it to $\frac{M}{1000}$ or 0.0065 per cent., but for more dilute solutions beyond that point the curve approximates a horizontal straight line. This, according to the Nernst theory, would mean that the number of zinc ions in such solutions remains nearly constant. In spite of all the irregularities in the curves, the point -3 or $\frac{M}{1000}$ or 0.0065 per cent.

KCy is evidently a critical or inflection-point in the curve.

The results obtained with high dilutions of cyanide and with distilled water were very uncertain, probably because of the formation of insoluble films of oxide of zinc and occluded hydrogen, which prevented the accurate reading of the needle.

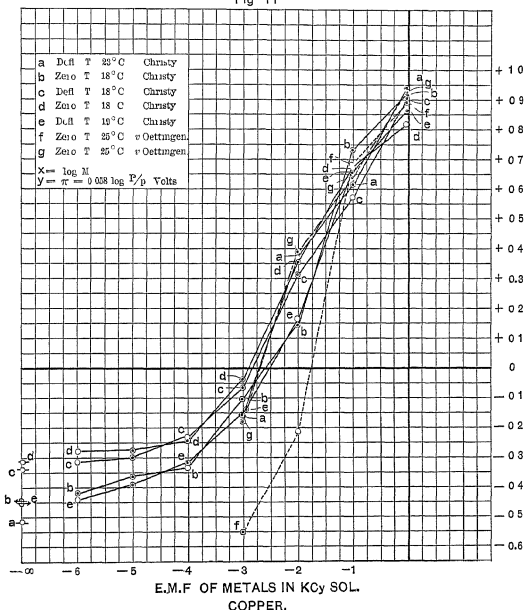
TABLE IV — *Electromotive Force of Copper (Burnished Sheet) in KCy*

Curve	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Note-book B1 page	68	178	188	189	190	Publish'd	Publish'd
Date	Oct 20, '96	Aug 30, '99	Sep 6, '99	Sep 6, '99	Sep 7, '99	Jan, '99	Jan, '99
Method	Deflect	Zero	Deflect	Zero	Deflect	Zero	Zero
Resis ohms	100,000		100,000		200,000		
Temperature	23° C	18° C	18° C	18° C	19° C	25° C	25° C
Observer	Christy	Christy	Christy	Christy	Christy	Von Oettingen	Von Oettingen
EMF (N E = -0.560)	Volts	Volts	Volts	Volts	Volts	Volts	Volts
Concentration							
KCy $\frac{M}{1}$	+0.930	+0.910	+0.905	+0.811 (?)	+0.880	+0.924	+0.890
$\frac{M}{10}$	+0.620	+0.781	+0.310	+0.663	+0.660	+0.680	+0.648
$\frac{M}{100}$	+0.370	+0.146	+0.310	+0.356	+0.149	-0.212	+0.380
$\frac{M}{1,000}$	+0.158	-0.104	-0.068	-0.048	-0.151	-0.550	-0.280
$\frac{M}{10,000}$		-0.382	-0.241	-0.230	-0.324		
$\frac{M}{100,000}$		-0.360	-0.299	-0.272	-0.387		
$\frac{M}{1,000,000}$		-0.426	-0.314	-0.282	-0.442		
$\frac{M}{\infty} (= H_2O)$	-0.560 (?)	-0.444	-0.328	-0.313	-0.450		

In my results with the deflection method, I have always taken the highest reliable reading as the most probable result. It was often quite difficult to make sure of the proper reading, as a slight insoluble film of cyanide of copper formed almost instantly, and this lowered the potential almost before a reading could be taken. On agitating the copper, so as to bring it into contact with fresh solution, the potential would gradually rise to a maximum, after which, on being left at rest, it would again fall off more gradually. It is possible, also, that the tendency of copper to form cupric, as well as cuprous cyanide, may in part explain the discordant results, such, for instance, as that obtained by Prof von Oettingen with $\frac{M}{100}$ KCy solution. He says in a footnote concerning this case, "On shaking, the potential suddenly rises from - 0.212 to + 0.380"

The results contained in Table IV. have all been plotted in Fig 11. The mean results of these curves show a tendency to follow the course of a straight line from $\frac{M}{1}$ down to $\frac{M}{1000}$; or perhaps to $\frac{M}{10,000}$; that is, from 6.5 down to 0.00065 per

Fig 11



On the horizontal (x) axis are laid off the values of $\log M = \log 10^a$, on the vertical (y) axis, the actual volts.

cent., when it breaks off sharply and runs along flat again, just as the zinc-curve did.

On plotting the gold-curves, as has been done in Fig. 12, it is evident that the gold follows the logarithmic law fairly well

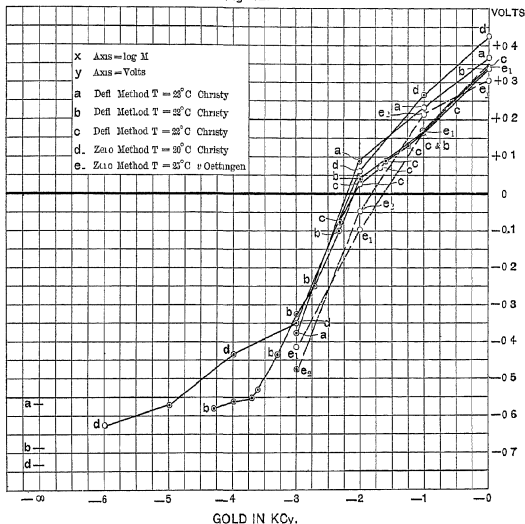
TABLE V.—*Electromotive Force of Gold in KCy Solutions.*

Curve	(a)	(b)	(c)	(d)	(e ₁)	(e ₂)
Note-book, B1, page	71	86	88	172	Published	Published
Date	Oct 20, '96	Dec 12, '96	Dec 14, '96	Aug 26, '99	Feb, '99	Feb, '99
Method	Deflect	Deflect	Deflect	Zero	Zero.	Zero
Resis ohms	100,000	50,000	50,000			
Temperature	23° C	22° C	22° C	20° C	25° C	25° C
Observer	Christy	Christy	Christy	Christy	Von Oettingen	Von Oettingen
EMF	Volts	Volts	Volts	Volts	Volts	Volts
(N E = -0.560)						
Concent'n KCy						
6.4M			+0.468			
3.2M			+0.420			
1.6M			+0.357			
M						
1	+0.366	+0.334	+0.336	+0.418	+0.340	+0.306
1						
M			+0.288			
2						
M			+0.239			
4						
M						
10	+0.233	+0.176	+0.178	+0.264	+0.180	+0.218
10			+0.135			
20			+0.093			
M						
40			+0.073			
M						
50						
M						
100	+0.087	+0.045	+0.037	+0.065	-0.092	-0.056
M		-0.099	-0.073			
200		-0.244				
M						
500		-0.326		-0.348	-0.414	-0.474
M	-0.380					
1,000		-0.436				
M		-0.533				
2,000		-0.554				
M		-0.560		-0.439		
4,000		-0.581				
M						
5,000						
M						
10,000						
M						
20,000			-0.567			
M			-0.622			
100,000						
M						
1,000,000						
M						
∞ (= H ₂ O)	-0.560 (?)	-0.698		Sep 4, '99		
				Deflection		
				-0.724		
				-0.620		
				-0.709		

as far as $\frac{M}{100}$ or 0.065 per cent. KCy. A considerable fall of potential occurs, according to my experiments, between $\frac{M}{100}$ and $\frac{M}{1000}$, or 0.0065 per cent. KCy, indicating an increase of osmotic pressure, probably due to an increasing dissociation of

the potassium aurous cyanide. This point seems again a critical point in the curve, which, beyond it, runs off more flatly, indicating an approach to a constant osmotic pressure of the gold ions.

Fig 12.



On the horizontal (x) axis are laid off the values of $\log M = \log 10^a$; on the vertical (y) axis, the actual volts.

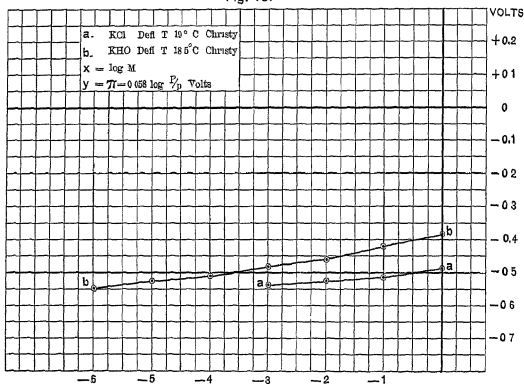
Electromotive Force of Gold in KCl and KHO.

In order to bring out the effect of the potassium cyanide in reducing the osmotic pressure of the gold ions in the solution (according to the Nernst theory), I append the following experiments on the electromotive force of gold in solutions of potassium chloride and potassium hydrate. These results are given in Table VI., and are plotted in Fig. 13. It is evident that there is a very much smaller electromotive force in each of these cases. It is particularly low in the case of potassium chloride. According to the Nernst theory, the solution-pres-

TABLE VI.—*Electromotive Force of Gold in KCl and KHO.*

Curve	(a)	(b)
Note-book B1, page	160	159
Date	Aug 10, '99	Aug 10, '99
Resistance, ohms	30,000	30,000
Temperature	19° C	18.5° C
Observer	Christy	Christy
EMF (N E = -0.560)	Volts	Volts
Solution	KCl	KHO.
Concentration		
M		
1	-0.487	-0.381
M		
10	-0.510	-0.422
M		
100	-0.523	-0.468
M		
1,000	-0.533	-0.486
M		
10,000		-0.505
M		
100,000		-0.526
M		
1,000,000		-0.551

Fig. 13.



E.M.F. OF GOLD IN KCl AND KHO SOLUTIONS.

On the horizontal (x) axis are laid off the values of $\log M = \log 10^n$, on the vertical (y) axis, the actual volts.

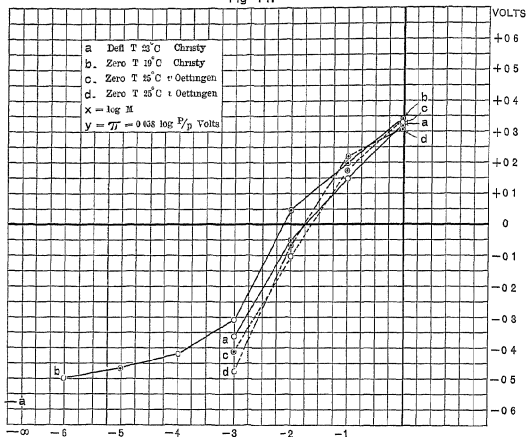
sure of the gold is the same in each of these solutions; that is, the pressure with which the gold tends to go into solution is exactly the same (at a given temperature), whether the gold is immersed in either potassium cyanide, potassium chloride or potassium hydrate. But the number of gold ions in each solution, and hence the resulting osmotic pressure, is very different. According to this theory, it is least in potassium cyanide, much greater in potassium hydrate, and greatest of all in potassium chloride. Consequently, the EMF varies inversely as p , according to the ratio $\log. \frac{P}{p}$.

The curves in both cases run rather flat, indicating an approach to a constant osmotic pressure for high dilutions.

TABLE VII.—*Electromotive Force of Silver in KCy.*

Curve	(a)	(b)	(c)	(d)
Note-book B1, page	71	170	Published	Published
Date	Oct 20, '96	Aug 19, '99	Jan, '99	Jan, '99
Method	Deflect	Zero	Zero	Zero
Resistance, ohms	100,000			
Temperature	23° C.	19° C	25° C	25° C
Observer	Christy	Christy	Von Oettingen	Von Oettingen
EMF (N E = -0.560)	Volts	Volts	Volts	Volts
Concentration KCy				
$\frac{M}{1}$	+0.326	+0.345	+0.340	+0.306
$\frac{M}{10}$	+0.152	+0.194	+0.180	+0.218
$\frac{M}{100}$	-0.054	+0.058	-0.092	-0.156
$\frac{M}{1,000}$	-0.360	-0.308	-0.414	-0.474
$\frac{M}{10,000}$. .		-0.417	.	
$\frac{M}{100,000}$		-0.457		.
$\frac{M}{1,000,000}$		-0.498		..
$\frac{M}{\infty} (=H_2O)$	-0.572	. .		.

Fig 14.



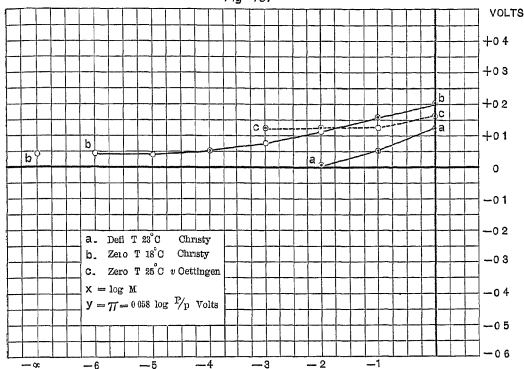
E M F OF SILVER IN KCy.

On the horizontal (x) axis are laid off the values of $\log M = \log 10^m$, on the vertical (y) axis, the actual volts

TABLE VIII — *Electromotive Force of Lead in KCy.*

Curve	(a)	(b)	(c)
Note-book B1, page	68	183	Published
Date	Oct 20, '99	Sep 2, '99	February, '99
Method	Deflect.	Zero	Zero
Resistance, ohms . . .	100,000		
Temperature	23° C	18° C	25° C
Observer	Christy	Christy	Von Oettingen.
EMF (N E. = -0.56)	Volts	Volts	Volts.
Concentration KCy			
$\frac{M}{1}$	+0.125	+0.200	+0.164 const
$\frac{M}{10}$	+0.050	+0.158	+0.128 "
$\frac{M}{100}$	+0.006	+0.112	+0.120 "
$\frac{M}{1,000}$ . . . . .	.	+0.070	+0.120 "
$\frac{M}{10,000}$ . . . . .	.	+0.046	.
$\frac{M}{100,000}$ . . . . .	.	+0.040	.
$\frac{M}{1,000,000}$ . . . . .	.	+0.040	.
$\frac{M}{\infty} (= H_2O)$ . . . . .	.	+0.040	.

Fig 15.



E M F OF LEAD IN KCy SOLUTION

On the horizontal (x) axis are laid off the values of $\log M = \log 10^n$, on the vertical (y) axis, the actual volts.

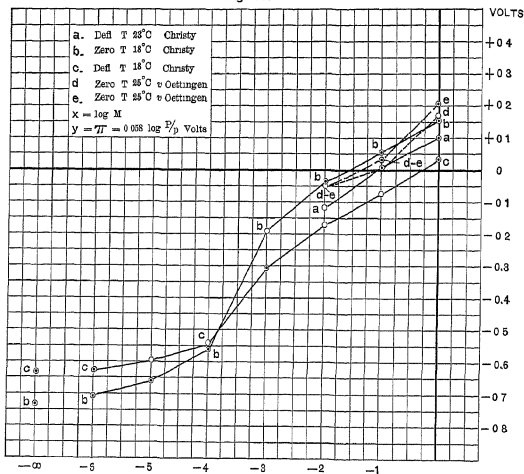
TABLE IX.—*Electromotive Force of Mercury in KCy.*

Curve	(a)	(b)	(c)	(d)	(e)
Note-book B1, page	67	184	184	Published	Published
Date	Oct 19, '96	Sep 2, '99	Sep 2, '99	Feb, '99	Feb, '99
Method.	Defect.	Zero	Defect	Zero	Zero
Resistance, ohms	100,000		100,000		
Temperature	23° C	18° C	18° C	25° C.	25° C
Observer	Christy.	Christy	Christy	Von Oettingen.	Von Oettingen
EMF (N E = -0.560)	Volts	Volts	Volts	Volts.	Volts.
Concentration KCy					
$\frac{M}{1}$	+0.091	+0.154	+0.032	+0.162	+0.200
$\frac{M}{10}$	+0.010	+0.047	-0.073	+0.008	+0.024
$\frac{M}{100}$	+0.115	-0.043	-0.176	-0.056	.
$\frac{M}{1,000}$		-0.193	-0.309	.	.
$\frac{M}{10,000}$		-0.560	-0.545	..	..
$\frac{M}{100,000}$		-0.664	-0.594		.
$\frac{M}{1,000,000}$		-0.705	-0.634	.	..
$\frac{M}{\infty} (= H_2O)$	.	-0.735	-0.640		

The normal electrode, checked on $\frac{M}{1}$ KCl, showed -0.560, as it should do

As a check on the foregoing results, I am able to quote the observations of an independent observer, Brandenburg *. He conducted a number of experiments with mercury in various depolarizing solutions. Instead, however, of using Ostwald's normal electrode, he used as one electrode mercury covered with sulphate of mercury (instead of the chloride used in Ostwald's). This electrode was then connected, by means of a siphon con-

Fig. 16.



E.M.F. OF MERCURY IN KCy SOLUTION.

On the horizontal (x) axis are laid off the values of $\log M = \log 10^a$, on the vertical (y) axis, the actual volts

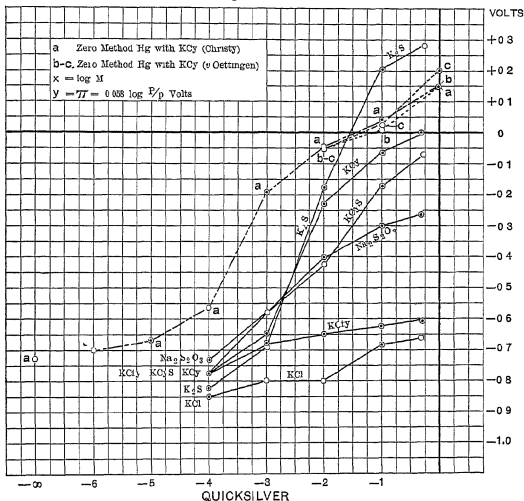
taining a neutral salt in solution, with a vessel containing mercury covered with the various solutions to be experimented on.

The solutions he experimented on to find their ion destroying-power, or their power to form complex ions with mercury, were potassium sulphide, potassium cyanide, potassium sulphocyanate, sodium hyposulphite, potassium ferrocyanide and potassium

* *Zeitschrift für Physikalische Chemie*, xi., p 570, etc

chloride. As he did not use the same strengths that I have found most convenient, I have had to plot his results, reduce them to zero potential,* and interpolate the results for the strengths I have used. The results so obtained are compared

Fig 17



Mercury Depolarizer/ HgSO_4/Hg .

The Results of Brandenburg, (Z f Ph Ch. xi 570 &c)

Plotted, Interpolated, Replotted and Reduced to 0 Potential, by S B Christy

To which are added, for comparison, curves with Normal Electrodes

On the horizontal (x) axis are laid off the values of $\log M = \log 10^n$; on the vertical (y) axis, the actual volts.

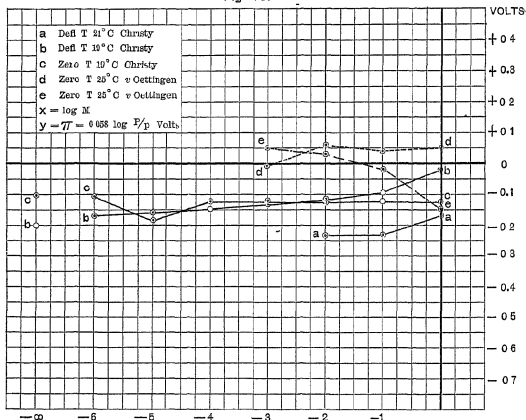
with the results obtained by Professor Oettingen and myself with the normal electrode. The results obtained by us for potassium cyanide are higher than Brandenburg's, but show the curves to be of the same general nature. They are shown in Fig. 17.

* On the supposition that $\frac{\text{Hg}}{\text{Hg}_2\text{Cl}_2}$ has a potential of -0.98 instead of -0.560 for $\frac{\text{Hg}}{\text{Hg}_2\text{Cl}_2}$

TABLE X—*Electromotive Force of Iron in KCy.*

Curve	(a)	(b)	(c)	(d)	(e)
Note-book B1, page	68	182	180	Published	Published
Date . . .	Oct 21, '96	Sep 1, '99	Sep 1, '99	Feb, '99	Feb, '99
Method . . .	Deflect	Deflect	Zero	Zero	Zero
Resistance, ohms	100,000	100,000	..		
Temperature	21° C	19° C	19° C	25° C	25° C
Observer	Christy	Christy	Christy	Von Oettingen	Von Oettingen
EMF (N E = -0.56)	Volts	Volts	Volts	Volts	Volts
Concentration KCy					
$\frac{M}{1}$	-0.169	-0.028	-0.124	+0.56	-0.146
$\frac{M}{10}$..	-0.236	-0.082	-0.124	+0.34	-0.120
$\frac{M}{100}$	-0.236	-0.116	-0.124	+0.054	+0.022
$\frac{M}{1,000}$. .		-0.131	-0.124	-0.008	+0.050
$\frac{M}{10,000}$.		-0.146	-0.124		.
$\frac{M}{100,000}$. .		-0.160	-0.184	.	.
$\frac{M}{1,000,000}$.		-0.160	-0.104		
$\frac{M}{\infty} (= H_2O)$		-0.206	-0.104	.	

Fig 18.



E.M.F. OF IRON IN KCy SOLUTION.

On the horizontal (x) axis are laid off the values of $\log M = \log 10^n$; on the vertical (y) axis, the actual volts

In order to bring out more clearly the nature of the relations existing between EMF of the different metals, I have combined, from the plotted curves of each metal, what appear to be the most probable values for each metal. These results are contained in Table XI.

TABLE XI.—*Electromotive Force of Metals in Cyanide of Potassium Solution*

CONCENTRATION		COMBINATION OF MOST PROBABLE VALUES						
M = 10 ^a	Log 10 ^a	Zinc	Copper	Gold	Silver	Lead	Mercury	Iron
M = 10 ⁰	0	+0 945	+0 930	+0 420	+0 340	+0 200	+0 150	-0 030
M = 10 ⁻¹	-1	+0 870	+0 880	+0 285	+0 195	+0 160	+0 050	-0 090
M = 10 ⁻²	-2	+0 775	+0 430	+0 090	+0 055	+0 110	+0 040	-0 120
M = 10 ⁻³	-3	+0 415	-0 050	-0 340	-0 310	+0 070	-0 190	-0 130
M = 10 ⁻⁴	-4	+0 385	-0 250	-0 450	-0 420	+0 050	-0 580	-0 140
M = 10 ⁻⁵	-5	+0 355	-0 270	-0 565	-0 460	+0 040	-0 600	-0 150
M = 10 ⁻⁶	-6	+0 330	-0 280	-0 620	-0 495	+0 040	-0 635	-0 160
Dist water	-∞	+0 280	-0 320	-0 720	-0 570	+0 040	-0 640	-0 200

These results have been plotted in Fig. 19. These curves all show critical points at either log. M = -2, -3 or -4. Most of them show the greatest amount of inflection at log M = -3. In fact, most of them seem to change in character at this point. According to the Nernst-Ostwald theory, this would be explained by the assumption that below say $\frac{M}{1000}$ KCy, the dissociation of the complex ion containing the metal in point is practically complete, so that the osmotic pressure p of the given metallic ions in the dilute solutions becomes practically constant below this point, so that as the ratio $\frac{P}{p}$ is nearly constant, so its logarithm, and hence the voltage, becomes also nearly constant, as is shown in the figure.

The curves for lead and iron are very remarkable, at first quite low, they maintain themselves at a higher level than either of the other metals except zinc. This is explainable on the supposition that the values of P for lead and iron are for these metals rather low, but that the values of p reach a nearly constant value sooner than for the other metals, so that the resulting curves flatten earlier.

These curves also show a number of remarkable crossings.

It will be observed that the metals change their sequence from that of zinc, copper, gold, silver, lead, mercury, iron, which they possess in a $\frac{M}{I}$, or 6.5 per cent. KCy solution, to the order zinc, lead, iron, copper, silver, mercury, gold, in distilled water, which is the usual electrochemical series in acid solutions quoted by Wilson except that iron is placed above lead. The determination of iron in my experiments was not entirely satisfactory, by reason, apparently, of the formation of films, and the results are probably too low. Water, also, appears to act like a weak alkali.

All the metals show a critical point somewhere between $\log M = -3$ and -4 , at which dilution they seem to change from the voltage due to the cyanide solution to that which they ordinarily possess.

From a study of these curves there seems to be little support for the so-called "selective affinity" of dilute cyanide solutions for gold and silver, except in the case of copper down to $\log M = -4$, or 0.00065 per cent. KCy. In the case of zinc, lead, iron and mercury the strong solutions give a better relative voltage in favor of the gold than do the dilute cyanide solutions. But in the case of copper, there seems to be a distinct advantage in favor of the gold in dilute solutions down to 0.00065 per cent. Then the curves widen again. These facts will appear from the following table taken from the figure.

TABLE XII.—*Differences in Electromotive Force Between Gold and Copper in Potassium Cyanide Solutions*

$\log M = \log 10^n$	Value of 10^n	KCy	Difference Between Gold and Copper
		Per cent	Volts
0	1 — 1	6.5	0.51
-1	1 — 10	0.65	0.42
-2	1 — 100	0.065	0.32
-3	1 — 1,000	0.0065	0.30
-4 	1 — 10,000	0.00065	0.20
-5 .	1 — 100,000	0.000065	0.30
-6 .	1 — 1,000,000	0.0000065	0.34
$-\infty$	1 \div Infinity (H_2O)	0	0.40

It should be remarked that if we had an independent method of determining the number of metallic ions in cyanide solu-

tions, and were thus able to plot the EMF in terms of the actual ionic concentration instead of the molecular concentration, we should probably reach a more perfect agreement with the logarithmic law than in the curves here shown. Nevertheless, even as it is, a general agreement is certainly evident.

Relation Between the Strength of Cyanide Solutions and Their Dissolving Power.

It has already been shown by MacLaurin,* that the dissolving power of a cyanide solution saturated with oxygen increases with its strength until a strength of 5 or 10 per cent. is reached, and diminishes again as the strength in cyanide increases beyond that point. But, so far as I am aware, no one has proposed the question "At what point of dilution does the cyanide solution cease to act on the gold?"

According to the Nernst theory, gold should cease to dissolve in cyanide solutions, *provided no force acts except its own solution-pressure*, at the point at which its electromotive force is zero, for then its solution-pressure will be just balanced by the osmotic pressure of the ions already in solution. At this point (provided no other force acts) the solution of the gold should cease.

It seemed interesting to ascertain if there were such a point. In order to do so, it was necessary to expose the gold to the cyanide solution, in the presence of air, under circumstances most favorable for rapid solution. Hence I devised a rotating apparatus, consisting of three pairs of rollers, driven by a small Pelton water-motor, on which a couple of $2\frac{1}{2}$ -liter bottles, such as are used for holding nitric acid, could be laid and rotated about their long axes. The number of revolutions of the middle axis being recorded, the distance traveled was known. This precaution was taken to be able to allow for the irregularities of the motor.

Standard strips of fine gold were prepared by repeated precipitation with sulphurous acid from a diluted chloride solution. These were rolled out thin and cut to a standard size of 2 in by $\frac{1}{4}$ in. They weighed from 250 to 330 mg., according to their thickness. The strips were boiled in sulphuric and muriatic acids, washed, and ignited before use. The first set of experiments was undertaken with 2 liters of solution and $\frac{1}{2}$ liter

* *Journ Chem Soc*, lxiii, p. 731.

of air, the bottles being stoppered. The weighed gold strips were then added, the bottles were rotated for 24 hours, and the strips were then washed and dried and weighed again. The number of rotations made in 24 hours ranged from 4000 to 24,000, and as the interior diameter of the bottles was $4\frac{1}{2}$ in., the distance traveled in this time by the gold strip was from one to six miles. It was found impossible to get a uniform rotation-rate, owing to constant changes in the water supply. But so long as the solution was kept gently agitated these variations did not seem to have any appreciable effect on the result.*

Table XIII. shows the results of these experiments. The first pair were undertaken with distilled water, to see if there was any loss due to erosion. The apparent loss of 0.01 mg. was almost at the limit of accuracy of the balance, but seemed to show the possibility of a slight loss due to that cause. It will be observed that up to $\frac{M}{2000}$ or 0.00325 per cent. the gold-loss is merely nominal, never more than 0.29 mg., often zero, and the results vary in the most irregular manner. No. 18, with $\frac{M}{10,000}$ or 0.00065 per cent., gave a loss of zero, and No. 20, with $\frac{M}{4000}$ or 0.0016 per cent., only 0.08 mg. It is believed that these small losses below $\frac{M}{4000}$ were chiefly mechanical. It was noted that while most of the bottles used were perfectly smooth inside, some seemed to have small sharp grains of sand, or slivers of glass, projecting above the smooth inner surface. In many cases it was impossible to detect these without breaking the bottles. The loss in No. 12, which was not rotated, cannot be set down to this cause. The explanation in this case, and perhaps in some others, may have been an imperfect mixing of the solution. The solutions were made up by adding the proper volume of strong solution to the proper amount of distilled water. In case the mixture of the solutions was not thoroughly made before the gold strip was added, the gold

* In making these solubility-experiments, I was aided by my former assistant, now Assistant Professor, E. A. Hersam. I wish also to acknowledge the aid of my present assistant, Mr. Geo. E. Young, in the preparation of the standard solutions used in these experiments, and of the illustrations.

TABLE XIII—*Solubility of Gold in Cyanide of Varying Strength*

In twenty-four hours Gold strips, standard size Fine gold, 2 in x $\frac{1}{2}$ in Weight, 250 to 330 mg $2\frac{1}{2}$ liter bottles, $4\frac{1}{2}$ in diameter, making 4000 to 24,000 revolutions in twenty-four hours, and containing 2 liters cyanide solution and $\frac{1}{2}$ liter air

No	Strength of Cyanide	KCy Per Cent	Revolutions in 24 Hours	Loss Gold in 24 Hrs., Milligrams	Remarks
1	$\frac{M}{20} = (H_2O)$		24,461	0 01	New strip
2	$\frac{M}{\infty} = (H_2O)$		18,595	0 01	
3	$\frac{M}{100,000}$	0 000065	15,403	0 01	$2\frac{1}{8}$ of 0 2 milligramme, the loss in 46 hours
4	$\frac{M}{100,000}$	0 000065	10,344	0 008	
5	$\frac{M}{60,000}$	0 000109	23,750	0 00	
6	$\frac{M}{50,000}$	0 00013	14,430	0 00	
7	$\frac{M}{50,000}$	0 00013	11,315	0 06	
8	$\frac{M}{40,000}$	0 00016	7,920	0 02	
9	$\frac{M}{40,000}$	0 00016	8,490	0 11	
10	$\frac{M}{40,000}$	0 00016	10,180	0 19	
11	$\frac{M}{30,000}$	0 000216	14,850	0 02	
12	$\frac{M}{30,000}$	0 000216	{ Not rotated	0 11	
13	$\frac{M}{30,000}$	0 000216		0 29	
14	$\frac{M}{20,000}$	0 000325	6,490	0 20	$2\frac{1}{8}$ of loss in 45 hours
15	$\frac{M}{20,000}$	0 000325	17,746	0 01	
16	$\frac{M}{20,000}$	0 000325	17,746	0 025	Same as above
17	$\frac{M}{10,000}$	0 00065	9,780	0 08	Treated 24 hours
18	$\frac{M}{10,000}$	0 00065	9,780	0 00	Duplicate of No 17
Total loss Nos 3 to 18 inclusive				1 133	Average loss, 0 07 mg
19	$\frac{M}{4000}$	0 0016	14,423	0 26	Mean loss, 0 17 mg
20	$\frac{M}{4000}$	0 0016	14,423	0 08	
21	$\frac{M}{2000}$	0 00325	14,423	9 68	Mean of two, 23 03 mg
22	$\frac{M}{1000}$	0 0065	4,260	24 86	
23	$\frac{M}{1000}$	0 0065	4,260	21 21	
24	$\frac{M}{500}$	0 013	5,790	81 74	Mean of two, 84 60 mg
25	$\frac{M}{500}$	0 013	5,790	87 48	
26	$\frac{M}{100}$	0 065	5,270	143 64	Mean of two, 146 91 mg.
27	$\frac{M}{100}$	0 065	5,270	150 18	

would at first be in a layer of stronger solution that might have a slight solvent effect until the dilution was effected by rotation. The fact that the mean loss up to $\frac{M}{10,000}$ is only 0.07 mg; that even at $\frac{M}{10,000}$ (Exp't No. 18), no loss, and in No. 20 a loss of only 0.08 mg. was obtained, renders it extremely probable that the solution-loss up to $\frac{M}{10,000}$ or 0.00065 per cent. is absolutely nil. *Thus much is certain these experiments demonstrate that for all practical purposes the cyanide of potassium solution ceases to act at a strength below 0.001 per cent*

Going to higher strengths we find a sudden jump at $\frac{M}{2000}$; here the loss has risen to 9.68 mg, and beyond this it rapidly increases; the strips in the $\frac{M}{100}$ or 0.065 per cent. solution being eaten through in 24 hours.

The next set of experiments was devised to show the effect of a smaller volume of cyanide solution, and an unlimited supply of air. The same bottles as before were used, but they contained only 500 cc. of solution, and were left open to the air so that the latter was free to enter. The results, as shown in Table XIV., are in general the same as before. No appreciable loss occurs up to $\frac{M}{2000}$, but at that point, and for greater strengths, the loss rapidly increases, finally rising a little higher than before. In Experiments Nos. 4 and 6 the entire solution was filtered and the washed filter was scorified and cupelled. In No. 4, where the gold-loss was 0.07, none was found. In No. 6 (the loss being 0.23 mg.), 0.02 mg. of abraded gold was found. Whether the rest was fine enough to pass the filter, or was dissolved before the strong solution was diluted, is a conjecture.

The next experiments were made without agitation and in the following manner: The gold strips were suspended in perforated glass tubes just below the surface of the solution, so that although the solution was at rest, circulation by convection was possible. The volume of the solution was 250 cc. The time of action was in each case 48 hours. The losses are

TABLE XIV — *Solubility of Gold in Potassium Cyanide of Varying Strength in Twenty-four Hours.*

Standard fine gold strips, 2 in $\times \frac{1}{2}$ in Weight, 250 to 330 mg $2\frac{1}{2}$ -liter bottles, $4\frac{1}{2}$ in diameter, making 4000 to 24,000 revolutions in twenty-four hours. Half a liter cyanide solution, 2 liters air Freely open to air

No	Strength of Cyanide	KCy Per Cent	Revolutions in 24 Hours	Gold Loss in 24 Hours, Milligrammes
1	$\frac{M}{\infty}$ ($= H_2O$)		5110	0 01
2	$\frac{M}{\infty}$ ($= H_2O$)		5110	0 00
3	$\frac{M}{12,800}$..	0 0005	8440	0 43 (!)
4	$\frac{M}{12,800}$..	0 0005	6600	0 07 ^a
5	$\frac{M}{6400}$. . .	0 001	8440	0 19
6	$\frac{M}{6400}$. . .	0 001	6600	0 23 [†]
7	$\frac{M}{4000}$. . .	0 0016	6790	0 16
8	$\frac{M}{3200}$. . .	0 002	5450	0 44
9	$\frac{M}{2000}$. . .	0 00325	6790	1 77
10	$\frac{M}{1600}$. . .	0 004	5450	4 29
11	$\frac{M}{800}$. . .	0 008	5540	48 43
12	$\frac{M}{400}$. . .	0 016	5540	74.96
13	$\frac{M}{200}$. . .	0.0325	28,230	150 54
14	$\frac{M}{100}$. . .	0 065	28,230	168.12

given in Table XV.; they are somewhat smaller than before, and again negligible below $\frac{M}{1000}$. In this case $\frac{M}{2000}$ was not determined. The advantage of the position near the surface near the air is well shown in comparing Nos. 5 and 8. When the gold was suspended near the surface of a $\frac{M}{400}$ solution, the loss was 21.44 mg. in 48 hours, or nearly half a milligramme

* In order to see whether or not these losses might not be due in part, or wholly due to abrasion, the solution was filtered and the filter scorified and cupelled. No gold was found in the filter

† This solution was also treated as above, and 0.02 mg of abraded gold was found.

per hour, when the strip was put at the bottom of the same volume of a similar solution, the total loss in the same time was only 8.70 mg, or hardly one-third as much.

TABLE XV.—*Solubility of Gold in Potassium Cyanide of Varying Strength in Forty-eight Hours. At Rest.*

Standard fine gold strips, 2 in. \times $\frac{1}{4}$ in Weight, 250 to 330 mg Suspended in open glass tubes, near surface of 250 c c cyanide solution at rest, but so that convection currents were possible

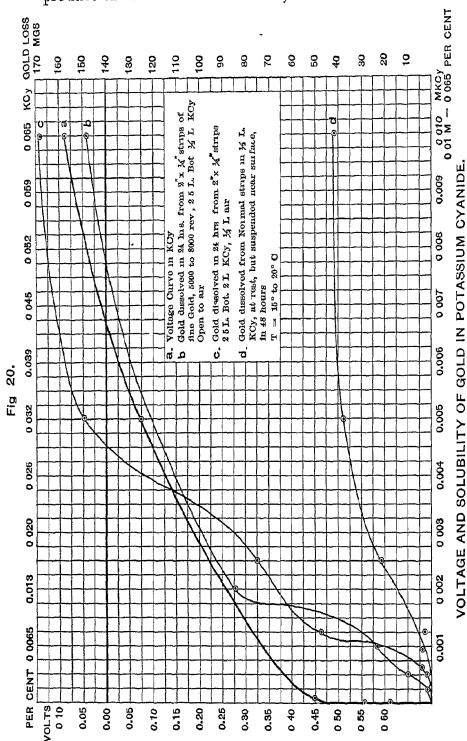
No	Strength of Cyanide	KCy Per Cent	Gold Loss in 48 Hours Milligrammes
1	$\frac{M}{100,000}$	0 000065	0 00
2	$\frac{M}{10,000}$	0 00085	0 06
3	$\frac{M}{1000}$	0 0065	4 33
4	$\frac{M}{800}$	0.008	3 86
5	$\frac{M}{400}$	0 016	21 44
6	$\frac{M}{200}$	0 0325	36 57
7	$\frac{M}{100}$	0 065	42 79

All these results have been plotted together with the voltage of the gold in curves *a*, *b*, *c* and *d*, in Fig. 20. According to the voltage-curve the voltage becomes zero for a cyanide solution of 0 00675 M, or about 0 044 per cent., and it is a curious fact that this is very near the limit of strength that practice has so far justified. Nevertheless, solutions as low as 0 01 per cent., and even less, have been employed in practice; and my experiments show that the solution acts perceptibly down as low as $\frac{M}{2000}$ or 0.00325 per cent., and perhaps to $\frac{M}{4000}$ or 0.0016 per cent KCy.

An Apparent Contradiction —Although it will be seen that the solubility-curves all follow very closely the voltage-curve, the fact that action does not cease for the zero of potential of gold

* 8 A similar experiment with same conditions as to strength and volume of solution as No 5, only that the strip of gold rested at the bottom of the vessel, gave a gold loss of only 8 7 mg.

in KCy solution seems to contradict the Nernst law. But this contradiction is only apparent and not real. It is part of the new theory that (except the infinitesimal amounts necessary to produce the state of static tension) ions cannot come into ex-

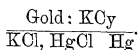


The values of MKCy on the lower margin, and the corresponding percentages of KCy at the top, belong to each fourth vertical line (i.e., to the 4th, 8th, 12th line, etc.) of subdivision. These lines should have been made heavier in the engraving.

istence or disappear except in pairs. That is, for every ion with a positive charge of electricity there must be one with an equal negative charge. Hence, when a positive ion appears, another positive ion must disappear, or else a negative one must also

appear simultaneously (In the case of ions with varying valency, an ion having a double or treble valency is, of course, equivalent to two or three oppositely electrified univalent ions.)

For instance, in my experiments for determining the electromotive force of gold in potassium cyanide solution against the normal electrode, the couple is composed of



When the gold dissolves, the positive gold ions travel from the gold with their positive charge, and in order that the solution may continue, a similar flow of positive ions must continue by means of potassium ions through the solution to the mercury. The potassium ions finally drive out some of the mercury ions which precipitate into the mercury forming the electrode, at the same time giving up their charge of positive electricity to it. Simultaneously there is a corresponding flow of negative ions in the opposite direction. Thus, first chlorine and then cyanogen move in the opposite direction to meet the gold, and the latter forms with the cyanogen the complex negative ion $(\text{AuCy}_2)(-)$. Thus $\text{Au}(+) + \text{Cy}(-) + \text{Cy}(-) = (\text{AuCy}_2)(-)$.

The action of this couple will go on so long as the electromotive force of the combination is greater than zero, and, as we have seen in my experiments, long after the electromotive force of the gold in the dilute cyanide solution has become zero. For the tendency of the mercury ions to discharge into the mercury electrode can only effect its purpose and cause a current by the simultaneous solution of the gold. That is, the tendency of the positively electrified ions of mercury to discharge themselves can cause the gold to dissolve long after its own electromotive force has ceased.

The Electromotive Force of the Oxygen of the Air the Sufficient Cause of the Solution of Gold in Cyanide Solutions

We have another substance at hand with a great tendency to form negative ions. This is the oxygen of the air. In the presence of water, the molecule of oxygen, O_2 , tends to assume the ionic state, combining with water to form four negatively electrified ions, thus, $\text{O}_2(\pm) + 2\text{H}_2\text{O}(\pm) = 4(\text{OH})(-)$. Or,

as has been suggested by Traube, when metals dissolve in the presence of oxygen, a molecule of the latter combines directly with two atoms of potentially nascent hydrogen thus $O_2 + 2H = H_2O_2$. Later, the peroxide of hydrogen dissociates into two negative hydroxyl ions, which, entering the solution with their negative charges of electricity, tend to produce a current in the same direction as the positively electrified mercury ions do when they leave the solution. That is, oxygen can play the same part in causing the solution of the gold as the mercury ions did in the normal electrode above cited.

The controlling importance of an abundant supply of oxygen is well shown by the curves in Fig. 20. In curve *c*, although there is only one-fourth as much cyanide present as in curve *b*, the amount of gold dissolved is greater, except for the very dilute solutions. The evident reason is that the aeration is greater. The cyanide-supply being ample in both cases, the oxygen-supply determines the rate of solubility. For dilute solutions, the amount of dissolved oxygen being sufficient in *b*, the greater volume of cyanide is the determining factor, and the amount dissolved in *b* is in this case greater than in *c*.

Interesting confirmation of these views is found in Maclaurin's experiments on the solubility of gold in a solution of cyanide of potassium saturated with oxygen.* He conducted two sets of experiments with gold strips in solutions of different strengths. The first set was left at rest for three hours, the second set was agitated. The losses are given in the following table.

TABLE XVI.—*Maclaurin's Table of Losses of Gold in KCy Saturated with Oxygen.*

At Rest in Solution Saturated with Oxygen Time, Three Hours

KCy, per cent .. .	1	5	10	20	30	40	50
Gold loss, mg † . . .	8 45	13 55	15 40	11 15	8 55	5 8	5 05

Agitated for Two Hours in Solution Saturated with Oxygen

KCy, per cent.. .	1	4 9	9 4	19 93	29 9	39	47 3
Gold loss, mg. † .	18 7	47.2	39 1	31 4	21 1	14 2	10 8

* *Journal Chemical Society*, LXIII, p 731

† Curve A, Fig 21

‡ Curve B, Fig 21.

Maclaurin deems the results in the second table more reliable than those in the first. In both it will be seen that there is a rapid increase of the dissolving power up to about 5 or 10 per cent. KCy; then it gradually falls off till at 50 per cent. the solubility of the gold is less than at 1 per cent.

The importance of the remarkable relation thus discovered by Maclaurin has, I think, never before been appreciated. Is it not a little remarkable that the strong cyanide solution should dissolve less gold than a weak one, while the electromotive force of the gold goes on steadily increasing?

But in the light of the new theory the reason is not far to seek, for at no time does the electromotive force of the gold rise high enough to displace without external aid any other positive ions, such as those of the potassium in the cyanide or the hydrogen in the water; and unless this be done, the gold ions cannot continue to form, nor the gold to dissolve. For this reason (as Maclaurin, myself and others have shown), in the absence of oxygen or some equivalent agency, gold does not dissolve in cyanide solutions. In other words, unless some negative ion like (OH) (—), (Cl) (—), or (Br) (—) is added, or some other positive ion as (K) (+) etc. is removed by some external source of energy, the action cannot go on. Ordinarily the oxygen of the air furnishes this energy; as we have seen above, it dissolves in the solution and furnishes the negative ions necessary to cause the solution of the gold.

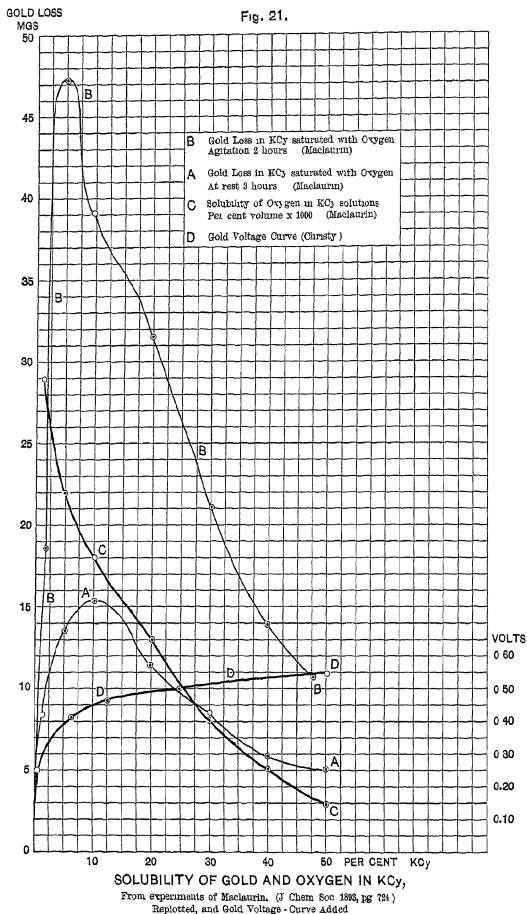
Again, Maclaurin has found the key to the anomalous action of strong cyanide solutions. It is in the fact which he demonstrated, that oxygen is less soluble in strong than in weak cyanide solutions. The following results for the solubility-coefficient of oxygen in KCy are plotted from his curves by interpolation.

TABLE XVII.—*Solubility of Oxygen in Solutions of KCy at 18° C.*
(*Maclaurin*)

Strength KCy, per cent	1	5	10	20	30	40	50
Solubility, per cent .	0 0295	0 0235	0 019	0 014	0 0103		
Solubility, per cent *	0 0290	0 022	0 018	0 013	0 008	0 005	0 003

* Curve C, Fig 21

Fig. 21.



I have replotted the results of the above experiments of MacLaurin so as to make them more comparable with my own results. I have replotted both the gold losses of MacLaurin and the second of his oxygen solubility coefficients in Fig 21; and I have also added the voltage-curve for gold from my own experiments.

It is plain now, for the first time, why there should be a maximum solubility somewhere between 5 and 10 per cent. There are two causes at work tending to dissolve the gold. First, the electromotive force of the gold itself, which alone is insufficient for the purpose, and second, that of the hydroxyl ions. If we suppose the latter proportional to the solubility of the oxygen, we see that the two forces operating to cause the solution of the gold tend to increase in inverse relation. Further, that the electromotive force of the gold rises very rapidly till it gets to between 5 and 10 per cent. and then rises very slowly after that, so that it has little effect on the solubility beyond that point. The solubility of the oxygen (and, as we have assumed, of the hydroxyl ions) is a maximum for pure water, and sinks as the gold-voltage rises. It is at between 5 and 10 per cent. that these two factors give their maximum effect. Beyond that point, the solubility-curves of the solution for oxygen and for gold run along nearly parallel.

Neither of these two factors alone is able to account for the maximum point in the solubility-curve. If the presence of oxygen were the only cause, the maximum solubility would be with dilute solutions. If it were alone due to the electromotive force of the gold, it would be greatest in strong solutions. As both act together, the maximum effect lies between these extremes.

As far as I am aware, this inverse relation between the electromotive force of gold, and that of oxygen in cyanide solutions of varying strength as a controlling factor in determining the solubility of gold in such solutions has never been brought out before. In a certain sense it is a turning-point in this discussion, and hence merits a little close attention.

The ionizing tendency of oxygen has been measured by a cell containing a platinum electrode made absorbent for oxygen by coating it with platinum sponge*. When this is im-

* Le Blanc, *Electrochemistry*, p 221

mersed in oxygen at atmospheric pressure, and the end of the wire is immersed in $\frac{M}{1}$ sulphuric acid, and the latter is connected with the normal electrode, the mercury dissolves, and a positive current flows through the solution from the mercury to the platinum with a potential of + 0.75 volt

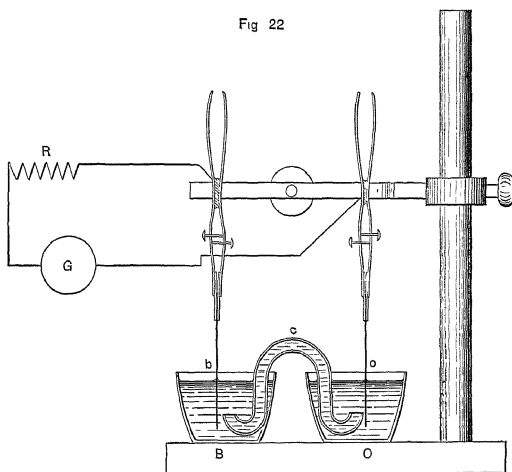
This current moves in the opposite direction to that due to the electromotive force of the mercury, viz. -0.560 volt; consequently the electromotive force of the oxygen at atmospheric pressure in contact with platinum sponge in $\frac{M}{1}$ sulphuric acid is equal to the sum of these, or 1.31 volts. It is negative, or -1.31 volts, since negative ions are produced, and the solution is negatively electrified by them.

If the above determination is correct, it follows that if, instead of the normal electrode in the above combination, we place a vessel containing a gold electrode and a solution of cyanide of potassium so weak that the potential of the gold is not merely zero, but as low as that of the mercury, viz. -0.560, it is plain that a similar voltage of + 0.75 should exist, but in this case the gold would dissolve instead of the mercury, and the positive current would flow through the solution from the gold to the platinum as before. In this case it would be, of course, necessary to interpose an $\frac{M}{1}$ solution of K_2SO_4 , KCl , or some other neutral salt, between H_2SO_4 and the KCy , to prevent their direct action with each other from interfering with the mere transfer of electromotive forces at the end of the line which we wish to effect.

Now gold does not absorb and ionize oxygen as readily as platinum does, but it acts similarly, though to a much less extent. In order to test the correctness of these views, I took two small porcelain cups, B and O, Fig. 22, in which were immersed the two electrodes *b* and *o*. These were gold strips held in platinum-tipped forceps, connected in series with a reflecting galvanometer G of 3000 ohms resistance, including that of the cell, and a resistance R of 30,000 ohms. The solution in either vessel is connected electrically by the liquid in the siphon C.

It is very difficult to prepare, and impossible to keep, a cyanide solution entirely free from oxygen, unless it is hermetically sealed. But the following method was selected as giving an approximation to it. A liter of distilled water was boiled under a filter-pump, and when most of the dissolved oxygen had been removed, cyanide of potassium was added, and the boiling was continued a few minutes, to drive out the air

Fig 22



APPARATUS FOR SHOWING THE
LOCAL ELECTROLYTIC ACTION
INVOLVED IN THE
SOLUTION OF GOLD IN
AERATED CYANIDE SOLUTION

absorbed during the solution of the cyanide. A cork was provided with two tubes like those of an ordinary wash-bottle, and after inserting the long tube below the surface, a layer of paraffine oil was floated on to the surface to exclude the air. The tip of the discharge-tube was kept closed by a cork when not in use. It was easy, by blowing in through the short tube above the surface of the oil, to discharge any required amount

of the solution as required, but of course each time this was done a small amount of air entered the solution. After cooling, the liquid was titrated and found to contain 0.62 per cent KCy. A similar 0.621 per cent. KCy solution was prepared and nearly saturated with oxygen. Through the galvanometer G and the resistance R, a Latimer-Clark cell gave a deflection of 7 scale-divisions. In vessel B were placed 12 c.c. of boiled 0.62 per cent. KCy solution and in O an equal volume of 0.621 per cent. KCy solution containing oxygen. On immersing the gold strips, the strip in B became negative, that is, the positive current flowed from B through the solution to O, with an EMF = +0.02 volt. When the liquid in both B and O was covered with paraffine oil to exclude the air, the EMF rose to +0.108 volt. On gently shaking electrode *o*, the EMF rose to +0.185 volt; on gently shaking B it fell to +0.08 volt (owing to absorbed oxygen). On cutting out the 30,000 ohms resistance, leaving that of the galvanometer (3000 ohms), the deflection rose to 6.5 scale-divisions, coming back again on inserting the resistance R to 0.6 scale-division or +0.12 volt. This gradually fell to 0.2 scale-division or +0.04 volt, where it remained for two hours. At the end of that time the resistance was cut out and the deflection rose to 2.5 scale-divisions, then, on shaking, 0 to 12 divisions; and then sank again to 2.7, where it remained fairly steady for two hours longer. At the end of this time, four hours in all, the electrodes were removed and cleaned with gasoline and ether from the oil and solution; and it was found that the electrodes had lost weight as follows:

b lost 1.28 mg.

o lost 1.73 mg.

The solutions contained in the vessels B and O and in the siphon C were also assayed with the following results

B contained 1.25 mg., O contained 1.68 mg., and C contained 0.06 mg. of gold.

The total loss of the electrodes was 3.01 mg., and that found was 2.99 mg. The difference of 0.02 mg. was probably lost in the washings of the electrodes, which were not saved.

This experiment, corroborated by many others, shows clearly that the positive current flows from the deoxygenated to the

oxygenated cyanide, just as theory would indicate. The fact that more gold has dissolved in the oxygenated than in the de-oxygenated cyanide does not militate against the indication of the galvanometer.

The solution of the gold in the vessel O is evidently due to the well-known phenomenon of "local action." The current that flows through the siphon has to overcome a resistance of from 3000 to 33,000 ohms, while local action can go on in the vessel O wherever an OH (—) ion comes in contact with gold and KCy. Here it forms a "short circuit," and it completes itself on the gold strip *o* at any point free from oxygen, without having to pass through the entire external circuit.

It might be objected that the fact that 1.73 mg. of gold had dissolved in O as against 1.28 in B only went to prove that some oxygen had been contained in B, though less than in O, and that the solution in each had been simply in proportion to the oxygen present. But this does not account for the absolute verdict of the galvanometer, which shows that the positive current flowed during the entire experiment from strip *b* through the solution to the strip *o*. The only explanation that remains is the one which I have suggested. There is no doubt that considerable local action went on in cell O. That this was the case is also evidenced by the fact that the action was more uniformly distributed over the surface of *b*, while the strip *o* was not uniformly acted on, but was eaten into in a remarkable manner. These strips, and particularly some of those to be described later (with peroxide of hydrogen), were not corroded most upon the edges where one would naturally expect it, but along vertical lines running up and down the middle of the strip. In some cases they were eaten through along these lines in such a manner that nothing remained but a thin film like gold lace. It appeared that local action started in along these lines rather than at the edges, owing to differences of potential due to the distribution of the oxygen, and that when it had once set in, it was able to maintain itself.

It is probable that in all cases of the solution of gold in aerated cyanide solutions the process, as in the above case, is one of local electrolytic action, though, as it is impossible in such a case to apply the galvanometer, it would be difficult to prove this proposition except by inference.

In all such experiments it is important to be certain that the gold strips are in the same physical state, since the existence of microscopic films or unweighable traces of occluded gas cause an appreciable difference of potential in apparently similar gold strips. This is best tested by comparing the strips in the same solution. They react similarly if they are carefully cleaned with boiling acid, and are then washed with distilled water and ignited to redness side by side in the muffle or over a Bunsen flame in a small porcelain dish. But if they are heated in different parts of the same Bunsen flame, they frequently show quite appreciable differences of potential due to occluded gases.

The Effect of Hydrogen Peroxide

The peroxide of hydrogen used was Marchand's medicinal, containing 3.3 per cent of available peroxide, as determined by titration with permanganate of potassium. According to the new theory, the H_2O_2 (\pm) takes up from the gold strip *o*, which becomes positive, two units of negative electricity and dissociates into 2 (OH) ($-$)

In the first experiment a $\frac{M}{I}$ KCy solution containing the usual amount of absorbed oxygen was used, and 10 c.c. of this solution was placed both in B and in O. Gold strips *b* and *o* were then placed in B and O, and the siphon was inserted. Both strips showed themselves of the same potential. The siphon was removed and 5 c.c. of water was added to B and 5 c.c. of hydrogen peroxide to O. On inserting the siphon and the electrodes, *b* proved to be electronegative, that is, the solution in B was electropositive by + 0.66 volt, in other words, the positive current flowed through the solution from *b* to *o*.

Another experiment was made with boiled water with 0.62 per cent. KCy that had been kept under $\frac{1}{8}$ in. of oil for a week. B and O were each filled with 10 c.c. of this solution, and the gold strips and siphon were inserted. The strips proved to be of the same potential. The siphon was then removed, and to B was added 2 c.c. of distilled water, and to O two c.c. of peroxide of hydrogen. After mixing, on replacing the siphon, the voltage rose to + 0.57 volt. That is, the positive current

flowed through the solution from *b* to *a*. To exclude the air, a layer of paraffine oil about $\frac{1}{8}$ -in. thick was floated over each solution before inserting the siphon.

The resistance of 30,000 ohms was then cut out, leaving only that of the galvanometer (3000 ohms), and the needle which had previously shown a deflection of 2.6 scale-divisions was thrown out of sight (The limits of the scale used were 21.0 scale-divisions.) After being thus short-circuited for an hour and a half, on throwing in again the 30,000 ohms resistance, the voltage of the combination showed itself to be still in the same direction, + 0.63 volt. The 30,000 ohms were again cut out and the combination was again short-circuited overnight. In the morning some bubbles of gas from the action of the peroxide had collected in the upper part of the siphon, and had nearly cut off the current. But on removing and refilling the siphon the voltage still showed itself to be in the same direction, + 0.55 volt. The resistance of 30,000 ohms was again cut out and that of the galvanometer only left in, and after $5\frac{1}{2}$ hours more the electrodes were taken out and cleaned and weighed. Total time, 23 hours.

The strip contained in B had lost 13.25 mg., while that in O had lost only 9.20 mg. *Evidently, in spite of the local action that had taken place in the vessel O, more gold had dissolved in the vessel B in the absence of the oxidizing agent, than in O where the oxidizing agent was present.*

In order to determine how much of the loss in B might be due to dissolved oxygen which had leaked through, or by, the oil-cover into the cyanide solution since it had been made, a week previously, 10 c c of the same solution as that used in B was placed in a similar vessel, and a gold strip was immersed in it half-way, and the liquid was then covered with the paraffine oil just as had been done in B and O. After $19\frac{1}{4}$ hours it had lost 4.28 mg. A similar strip entirely submerged below solution and oil lost, in 24 hours, 2.64 mg. These experiments prove that some air had leaked through, or by, the oil cover. It had been previously proved that if a thicker layer were used, it was possible practically to prevent altogether the ingress of oxygen and the solution of the gold. In this case it was inconvenient to use a layer thicker than $\frac{1}{8}$ -in. But the experi-

ment also clearly shows that the amount of gold thus dissolved by absorbed oxygen is so much less than that shown by the *b* strip, that the solution must have been caused by the electromotive forces of the combination in the manner I have explained.

The same experiment was repeated exactly as before, except that to 10 c.c. of 0.62 per cent. KCy in B was added 1 c.c. of water and to 10 c.c. in O was added 1 c.c. of peroxide of hydrogen. At first the voltage was + 0.652 volt, rapidly falling to + 0.63 volt. After cutting out all but 3000 ohms resistance for 21 hours, the voltage, on adding the 30,000 ohms, proved to be still + 0.63 volt. After again cutting out the 30,000 ohms for 27 hours, it still showed, on inserting it again, + 0.434, rising after resting a few minutes to + 0.456 volt. At this point, after a total of 47 hours, the electrodes were cleaned and weighed, and *b* was found to have lost 24.06 mg and *o* to have lost only 13.25 mg. *Here, again, the positive current has moved through the solution from b to o, and more gold has dissolved in the vessel containing no oxidizer, than in the one containing the oxidizer.*

In some other experiments with peroxide of hydrogen, there was more local action in O, and the *o* strip lost as much, and in some cases even twice as much, as the *b* strip. The exact conditions governing this local action are still under investigation. *But in these cases, also, the galvanometer showed that the positive current was still flowing through the solution from the strip b to the strip o in contact with the cyanide containing the oxidizer, and thence back through the gold strip o back again to b, the place of beginning.*

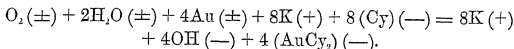
The course of the negative current may be traced from the gold strip *o* immersed in the oxygenated cyanide to the strip *b* immersed in the unoxygenated cyanide in two ways, as follows:

1. According to Ostwald* the reaction $O_2 + H_2 = 4OH$ produces $4 \times 21,100$ calories. Assuming this to be true, the oxygen molecule O_2 forms with the water four negative hydroxyl ions, 4 (OH) (—); these, assuming a negative charge from the electrode *o*, cause that end of the gold electrode to be positively electrified. Now these negative ions travel through the solution, displacing at the other end of the line four negatively electrified cyanogen ions, 4 (Cy) (—), which give up their

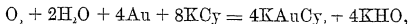
* *Chemische Energie*, p 956.

negative charge at the other gold electrode *b*, and thus enable four positive gold ions, 4 Au (+), to go into solution there, forming with eight cyanogen ions four complex negative ions, 4 (AuCy₂) (—)

The water present may be regarded as not dissociated appreciably, and the dilute solution of cyanide of potassium as entirely so. Making these assumptions, the principal reactions may be expressed as follows :

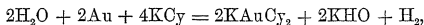


But this is equivalent to the so-called Ellsner reaction .



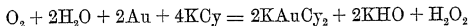
which Maclaurin* has proved to be quantitatively correct.

2. The other view, following Traube, has been urged by Bodlaender, of the Clausthal *Bergakademie*.† He shows first, in agreement with Maclaurin and myself, that the reaction

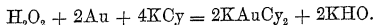


proposed by MacArthur to explain the solution of cyanide of gold in cyanide solutions, is incorrect. Next, he claims that the so-called Ellsner reaction really proceeds in two stages :

(a) The hydrogen, which is not formed according to MacArthur's reaction, is, in the presence of cyanide of potassium, water, gold and oxygen, potentially nascent; and a molecule of oxygen combines directly with two atoms of nascent hydrogen, forming hydrogen-peroxide, while two atoms of gold dissolve; —thus



(b) Next, the hydrogen peroxide gradually dissociates into hydroxyl, and causes the solution of two more atoms of gold thus .



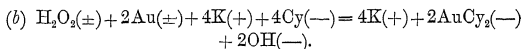
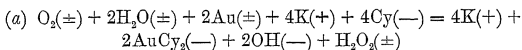
* *Journ. Chem. Soc.*, vol lxiu, p 728

† *Zeitschr f angewandte Chemie*, 1896, p 583.

The sum of these two reactions is, of course, the same as that of the Ellsner reaction, which correctly expresses the end-result.

When gold was rapidly dissolved in an aerated cyanide solution, Bodlaender was able to detect as much as 72.3 per cent of the hydrogen-peroxide required by reaction (a), and, as reaction (b) had probably already set in, this renders his explanation extremely probable.

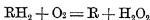
Expressed in terms of the ions, reactions (a) and (b) become:



The flow of ions through the solution is the same as in the first case. On the whole, the second seems the more probable explanation, though either agrees with most of the facts.*

* While this paper was in press, a paper on "Freiwillige Oxydation" (Auto-oxidation), by Dr. Manchot, of Goettingen, has appeared, in which he has examined the oxidation of a large number of phenol-derivatives, such as those used as developers in photography. One of these derivatives, oxanthranol, was particularly well adapted to give quantitative results, and he was able to prove that for every molecule of oxygen absorbed a molecule of hydrogen in the oxanthranol was oxidized, and a molecule of hydrogen-peroxide was formed.

Representing the organic radical by R, and the oxanthranol by RH_2 , he assumes that the reaction takes place as follows:



The organic radical, if unstable, is frequently still further oxidized in a second reaction by the hydrogen-peroxide thus formed.

It would appear that similar reactions ensue in the rusting of metals in damp air. The rusting of iron, zinc, etc., is worthy of thorough study in the light of these new ideas.

It would seem that the modern electrochemical views necessitate a return, in part at least, to the ideas of Berzelius and Schoenbein. They supposed that the same element was at times positively, and at other times negatively, electrified. This appears to be a consequence of the new view also. For if we regard the oxygen molecule $\text{O}_2(\pm)$ as electrically neutral, this can only be the case when one of its atoms has a double positive and the other an equal negative charge. By the attraction of these charges the molecule may be regarded as being held together. Its real composition then would be $\text{O}(-) + \text{O}(++)$. On the other hand, two atoms of oxygen in the elemental state would be similarly electrified with negative electricity, thus $\text{O}(-)$, $\text{O}(-)$, and would consequently repel

According to either of these views the new theory agrees quantitatively with the results of experiment, but offers for the first time a consistent explanation of its occurrence. *It is due to the superior electromotive force of the oxygen (or, in case they are present, to some other electronegative ions, as (OH) (—), Cl (—) Br (—), etc.), together with the capacity of the gold for forming complex ions with cyanogen.*

If instead of having the two ends of the gold strip immersed in two separate cyanide solutions, the strip is immersed in the same solution containing some dissolved oxygen, the same electrolytic action can still go on as a case of "local action;" for the couple



is still possible if we regard the gold to be short-circuited on itself, and the explanation given above still applies.

When I began this investigation in 1896, I marked out for myself a much wider range of investigation than here outlined, and the course of its partial execution has suggested many other interesting questions, some of which are still under investigation; but the constant and pressing interruptions of routine-work have made it impossible to carry the work further at the present time.

IV.—CONCLUSIONS.

Whatever may be the nature of the objections that may be raised against the final acceptance of the modern electrolytic theory in its present form, it will, I think, be conceded that the following conclusions may be fairly drawn from the foregoing

each other. Hence, to change an oxygen molecule into two oxygen atoms would require *four* units of negative electricity.

On the other hand, the hydrogen molecule would be composed as follows $\text{H}(+) + \text{H}(-)$, and to change it into two hydrogen atoms $\text{H}(+)$ and $\text{H}(+)$ would require *two* units of positive electricity.

It would also seem necessary to assume that there is an inherent tendency in the oxygen molecule (due, perhaps, to some peculiarity of shape or volume) to assume negative, and in the hydrogen molecule to assume positive, electricity in dissociating.

It would also appear as if a different result ought to be produced when neutral hydrogen molecules combine with a neutral oxygen molecule, from that which results from the combination of positively electrified hydrogen atoms with a neutral oxygen molecule. This may be the key to the formation of water in the one case and hydrogen-peroxide in the other.

1. That the new electrolytic theory explains in a remarkably complete manner the reason for the departure of metals immersed in cyanide solutions from the sequence of electromotive force which they present in acid solutions.

2. That it is the only theory ever presented that gives any clue to the remarkable aberration of cyanide solutions from all the usual chemical analogies.

3. That it explains in an entirely adequate manner the reason for the reactions that go on when gold, silver and other metals are dissolved and precipitated from cyanide solutions.

4. That the determination of the electromotive force of the metals in cyanide solutions under different conditions offers a means of research that is likely to be of great practical utility in determining the direction and intensity of chemical reactions, under fixed conditions, or in following them under changing conditions, just as they occur.

5. That the differences of electromotive force of metals in dilute cyanide solutions do not give much support to the so-called "selective affinity of dilute cyanide solutions for gold," the only common metal that shows any indication of such favorable action being copper.

6. It is probable that, in the absence of external electromotive forces, an aerated cyanide solution less than $\frac{M}{10,000}$ or 0.00065 per cent. is without action on metallic gold.

7. That for all practical purposes, an aerated cyanide solution of less than 0.001 per cent. is without action on metallic gold.

This study has led apparently far afield from the practical side of the cyanide process; yet I hope that it may be of service in at least calling attention to the work of others who have toiled for many years in attempting to clear up some of the most subtle questions that have ever taxed the human mind. For I am firmly convinced that, in the long run, such work is always of the greatest practical service. In these days, the words of Ostwald have certainly come true

"The science of to-day is the practice of to-morrow."

**Deep-Level Shafts on the Witwatersrand, with Remarks on
a Method of Working the Greatest Number of Deep-
Level Mines with the Fewest Possible Shafts.**

BY THOMAS HAIGHT LEGGETT, JOHANNESBURG, SOUTH AFRICA

(Canadian Meeting, August, 1900)

I—THE DEEP-LEVEL SHAFTS.

THE gold-deposits of the Witwatersrand (*Anglice*, "White Waters' Range") are, as is well-known, more or less parallel and tilted sedimentary beds of quartz-pebble conglomerate impregnated with gold. These beds, however, are locally called "reefs"—a term equivalent in signification to the American "ledge"—and, like the latter, usually applied to lodes, though covering in practical usage all deposits of tabular form. The first developments of the reefs of the Rand were naturally made along their outcrops. Since the mining law of the Transvaal does not confer upon locators the "extralateral right," the property of each locator upon the outcrop or apex ends with the vertical planes drawn through the boundaries of the claim. Consequently those portions of the reefs which lie "on the dip," beyond these boundaries, are separately acquired by locating new surface-claims, and are usually to be mined only by means of vertical shafts, reaching the reefs at considerable depths. The term "deep-level properties" is given to such claims on the dip, and the "deep-level shafts" are the vertical shafts sunk in the hanging-wall of the Witwatersrand reefs, in contradistinction to the incline-shafts almost universally employed on the outcrop-properties.

Number and Distribution.—The accompanying diagram, Plate I., shows the number and depth of these deep-level shafts, completed or under process of sinking, up to January 1, 1900. A number of shafts already located upon new deep-level properties, but upon which no work has yet been done, are not included in this diagram.* Vertical shafts sunk upon outcrop-

* Practically no deep-level shaft-sinking has been done since Oct. 1, 1899.

properties to develop deep-level ground, as in the Wolhuter, the Treasury, the Simmer & Jack Proprietary, and other mines, are included, as these are properly deep-level shafts, although the area developed is part and parcel of an outcrop-company.

With the exception of the shafts of the deep-level properties, for which the writer is consulting engineer, the data regarding the remainder have been courteously furnished by the consulting engineers and mine managers in whose charge they are.

In some cases it will be noticed that no estimate of depth to the reef has been given, and that distances from the outcrop are only approximate. These uncertainties are due partly to the fact that this diagram has necessarily been compiled in Cape Town, while many engineers have left their maps and other office data in Johannesburg, where they are now inaccessible, and partly to faults, dikes or other underground disturbances which have so dislocated the reef as to make the engineer-in-charge most cautious about placing any estimate upon the reef-depth.

The tables on page 949 summarize this deep-level shaft-work to date. The shafts are grouped with reference, first, to their horizontal distance from the main reef outcrop; secondly, to the depth of the main reef from the surface; and, thirdly, to the row of deep-level properties in which they are located, those properties lying next to the outcrop mines constituting the first row. The general term "Main Reef" is used to designate the most northerly and hence the deepest reef to be cut by the shaft. In the central Rand this is the Main reef, in the eastern Rand it is the North reef, in the extreme eastern flank the Van Ryn reef, in the Western Rand the Bothas reef, and in the extreme western flank the Randfontein reef.

Irregularities of Reefs in Dip and Strike.—It will be noticed that there is a considerable difference in the depths of the shafts situated comparatively close to the outcrop. This is due to the great variation in the dip of the reefs near the surface. In order to obtain the average dip of the reef from the outcrop to any given shaft, the line in the latter representing the reef must be connected with the Main Reef outcrop (No. 1 at the top of the diagram). The reef-series flattens on the flanks of the Rand, both east and west, where the dip is sometimes as slight as 6° , and may be said to average from 18° to 20° . In the middle

In this diagram, the different shafts have been indicated by numbers, as it was impracticable to engrave the names on so small a scale. The following list gives these numbers in order, with the names of the corresponding shafts. The figures in parenthesis after each name give in feet the horizontal distance of the shaft from No. 1, the Main reef outcrop.

1 Outcrop of Main reef (called also, according to locality, North, Van Ryn, Botha's and Randfontein reef), 2 Nourse Deep, No 3 shaft (510); 3 Nourse Deep, No 1 shaft (520), 4 Village Main reef, east shaft (520), 5 Benoni, east shaft (750); 6 Nourse Deep, No 2 shaft (820), 7 Treasury, vertical shaft (850), 8 Bonanza, main shaft (920), 9 Lancaster, No 1 Botha shaft (1000); 10 Roodepoort Deep (now R U M R.) D. L. shaft (1000), 11 French Rand mines, new vertical shaft (1030); 12 French Rand mines, Van Hesseft shaft (1030); 13. Simmer and Jack Proprietary, No 3 D L shaft (1060), 14 Benoni, west shaft (1060), 15. Lancaster, No 2 Botha shaft (1125), 16 West Roodepoort Deep, west shaft (1200), 17 New Modderfontein, east shaft (1200), 18. Witwatersrand Deep, east shaft (1215), 19 Wolhuter, D L shaft (1223), 20 Rose Deep, No 1 (east) shaft (1310), 21 Witwatersrand Deep, west shaft (1350), 22 Vogelstruis Consolidated Deep, east shaft (1400); 23. Simmer and Jack Proprietary cyanide shaft (1420), 24 Crown Deep, No. 1 (east) shaft (1420), 25 Ferreira Deep, No 1 (east) shaft (1450), 26 Ferreira Deep, No 2 (west) shaft (1500), 27 Langlaagte Deep, No 2 (west) shaft (1500), 28 Geldenhuys Deep, No 1 (east) shaft (1550), 29 Village Main reef, main shaft (1550), 30 Jumpus Deep, No 1 (east) shaft (1670), 31 Glen Deep, No 1 (east) shaft (1700), 32 Vogelstruis Consolidated Deep, central shaft (1745), 33 Rose Deep, No 2 (west) shaft (1760); 34 Glen Deep, No 2 (west) shaft (1800), 35 Langlaagte Deep, No 1 (east) shaft (1850), 36 Main reef, west, east shaft (1900), 37 Simmer and Jack Proprietary, No. 1 D L shaft (1950), 38 Crown Deep, No 2 (west) shaft (2020), 39 Main reef Deep, west shaft (2040), 40 Geldenhuys Deep, No 2 (west) shaft (2070); 41 Jumpus Deep, No 2 (west) shaft (2150), 42 Vogelstruis Consolidated Deep, west shaft (2190), 43 Kleinfontein Central, west shaft (2300), 44 Robinson Central Deep, main shaft (2320), 45 Durban Roodepoort Deep, No 2 (west) shaft (2350), 46. Durban Roodepoort Deep, No 1 (east) shaft (2350), 47 Knight's Deep, Robertson shaft (2400), 48. Simmer and Jack Proprietary, No 2 D L shaft (2410), 49 Main reef, east shaft (2435), 50 West Roodepoort Deep, east shaft (2532), 51 Roodepoort Central Deep, main shaft (2600), 52 Knight's Deep, Connor shaft (2600), 53 Main Reef East and Deep, joint shaft (2700), 54 South Nourse Deep, No 2 (west) shaft (2870), 55 Kleinfontein Central, east shaft (3030), 56 South Nourse Deep, No 1 (east) shaft (3030), 57. Village Deep, No 1 (east) shaft (3100), 58 Robinson Deep, No 2 (west) shaft (3200), 59 Tudor, No 1 (east) shaft (3210), 60 Tudor, No 2 (west) shaft (3210), 61 Village Deep, No 2 (west) shaft (3400), 62 Lancaster, Botha central shaft (4000), 63 Cinderella Deep, main shaft (4000), 64 Robinson Deep, east shaft (4080), 65 Lancaster west, Botha Deep shaft (4100), 66 South Geldenhuys Deep, Milner shaft (4160), 67 Angelo Deep, west shaft (4260), 68. Angelo Deep, east shaft (4350); 69 Knight Central, west shaft (4470), 70 South Geldenhuys Deep, Rhodes shaft (4500), 71 South Rose Deep, Radd shaft (4540), 72. Simmer and Jack east, Hammond shaft (4830), 73 South Rose Deep, Clements shaft (4880), 74 Knight Central, east shaft (4937), 75 Simmer and Jack east, Lohse shaft (5080), 76 Simmer and Jack west, Howard shaft (5340), 77 Simmer and Jack west, Webb shaft (5640), 78 Jupiter, Sapte shaft (5650); 79 Jupiter Catlin shaft (6230), 80 Rand Victoria mines, Albert shaft (8090), 81 Rand Victoria mines and east, Union shaft (8100), 82 Rand Victoria east, Victoria shaft (8150), 83 Turf Club Syndicate, east shaft borehole (8565); 84 Turf Club Syndicate, west shaft borehole (8575).

The thin lines indicate the estimated ultimate depths of the shafts. The heavy portions show the depths sunk to date. Dotted lines between arrow-heads cover the depths within which the reef is assumed to lie. The following abbreviations are used. B R., Botha's reef, M R., Main reef, N R., North reef, V R., Van Ryn reef, S R., South reef.

TABLE I.—*Shafts Grouped According to Their Distances from the Main Reef Outcrop.*

DISTANCE FROM OUTCROP IN FEET		Number of Shafts
From	To	
0	1,000	9
1,000	2,000	27
2,000	3,000	17
3,000	4,000	9
4,000	5,000	11
5,000	6,000	4
6,000	7,000	1
7,000	8,000	
8,000	9,000	3
Total		81

TABLE II.—*Shafts Grouped According to Their Depths*

ULTIMATE DEPTHS IN FEET		Number of Shafts
From	To	
400	1,000	20
1,000	1,500	22
1,500	2,000	13
2,000	2,500	10
2,500	3,000	7
3,000	3,500	1
3,500	4,000	
4,000	4,500	2
4,500	5,000	3
	No estimate of depth	78
		3
Total		81

TABLE III.—*Shafts Grouped in Rows.*

Row	Number of Shafts	Average Distance from Outcrop Feet	ULTIMATE DEPTHS FEET		Average Ultimate Depth Feet
			From	To	
First row of deep-level properties, including Simmer and Jack outcrop . . .	54	1,730	430	2,505	1,189
Omitted from lack of data . . .	1				
Second row of deep-level properties . . .	21	4,162	1,920	4,100	2,611
Omitted from lack of data. . .	2				
Third row of deep-level properties . . .	3	8,113	4,000	5,000	4,500

NOTE.—Properties which correspond to the second row of deep-levels in distance from reef outcrop and depth of reef are placed in that category although they adjoin outcrop-properties

of the Rand it is much steeper, being from 50° to 60° , while in the Henry Nourse the dip is almost vertical, continuing so for nearly a thousand feet in depth, so that a single row of claims (the dimensions of one claim being 150 Cape feet* along the strike by 400 Cape feet on the dip) constitutes the major portion of the outcrop-property, while the Nourse Deep shafts are within a stone's throw of those of the outcrop-property, this being the only instance of the kind on the Rand. In this case, the extremely steep dip is due to unusually extensive intrusions of eruptive dikes, which have caused an excessive up-tilting of the strata, as is shown by the development work in the Nourse Deep property, where the normal dip of 25° to 30° is resumed at a distance from the outcrop and depth from the surface of less than 1500 feet.

The sedimentary strata of quartzitic sandstones composing the Witwatersrand have been so dislocated and twisted by faults and dikes as to cause very great variations in dip, making it essential to study each locality specially, when it is desired to lay out deep-level shafts. Even then, the estimate of reef-depth remains more or less uncertain, because these dislocations may exist underground with little or no surface-indication of their presence.

The general statement made above, that the reefs and enclosing strata dip more steeply in the middle of the Rand, at and near Johannesburg, and flatten on the flanks east and west, is subject to some local exceptions. Thus, on the east, in the New Chimes and Modderfontein mines, the dip is from 70° to 80° from the horizontal for a distance of several hundred yards, and on the west, in the Randfontein mines, where the dip averages about 60° for several miles along the strike, and in some places is vertical or even reversed. These exceptional steep dips on the flanks of the Rand are undoubtedly due to local faulting and displacement.

Methods of Locating Shafts—In locating, on such ground, deep-level shafts over the dip, the engineer must determine, if possible, to what depth the faulting has affected the normal dip, or, perhaps, displaced the reefs; and where the surface indications are not sufficient to permit a reasonably accurate

* One Cape foot = 1 033 English feet

estimate, he has no other course but to sink one or more preliminary diamond-drill bore-holes. There are, however, other reasons for such drilling before the sinking of such very deep shafts as will be required in the ground now about to be developed on the Rand. For hoisting from depths of 3000 ft. and more, the magnitude of the shaft-equipment is such that it must be ordered some months, if not years, before it is actually required, in order to avoid unnecessary delay in the work. It is vitally important to know, therefore, in advance, whether an engine to hoist from 3000, or from 4000, 5000 or 6000 ft., will be required. Development in the deep-level mines has already shown up-throws of the reef as great as 800 ft., and, on the other hand, there are instances in which the shafts have passed as far as that beyond the point where the reef was expected to be cut, without encountering it. While a single bore-hole has little value as a test of the gold-contents of the reef, it has the greatest value as regards the depth of the reef from the surface, provided the ground be not broken up to such a degree as to prevent the recognition of the reef when its position has been reached.

Even where the ground is thus broken, it is often the case that parallel reefs (such as the Livingstone reefs in the eastern part of the Rand, lying about 800 feet above the Main reef series) can be located with sufficient accuracy to form a fairly close estimate of the position of the Main reef series. It is, of course, better (and, in fact, it is the usual practice) to sink two bore-holes simultaneously, in order that if an irremediable accident should happen to one of them, or the drill in one should strike broken ground where the reef was expected, the desired information may be obtained from the other without the loss of time which a new boring would involve.

In 1899, before the war, reliable diamond-drill contractors could be found to sink bore-holes to 4000 ft at 42s. 6d. per ft throughout, equal to a cost of £8500, or, for two holes, £17,000, for drilling alone. This amount would be increased by £1000 for the pay of a core-attendant, office-expenses, etc., making the cost per hole at the above rates £9000, while the time occupied would be from ten months to a year. It is likely that these prices will be reduced in the future. But, although they seem very high, yet in comparison with the

expenditure for development and equipment of the first row of deep-level mines, which averages from £500,000 to £600,000 before a single stamp is dropped or an ounce of gold is recovered, this expense of preliminary exploration is not excessive. In fact, the most serious consideration is the time occupied, but this, in the majority of instances, is fully offset by the value of the information obtained.

For the purpose of calculating the ore-tonnage of any piece of deep-level ground, or of making a rough estimate of reef-depth, it may be said that underground developments, to date, warrant the assumption of an average dip of 30° in such ground.

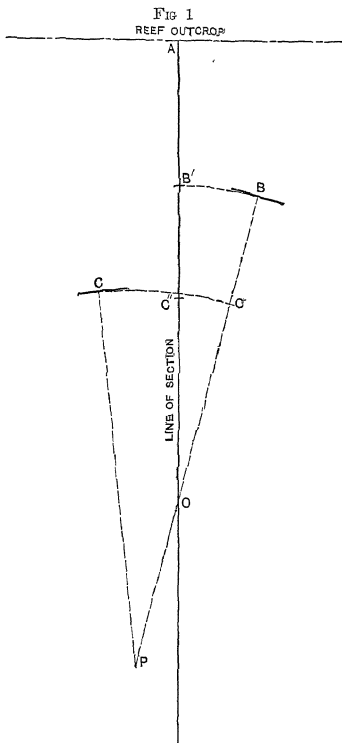
From the foregoing it is evident that, in estimating the approximate reef-depth in any given area of deep-level ground, it is necessary to be guided by the local conditions of dip at the outcrop, and in the immediate vicinity of the ground in question. The method adopted for such estimates of reef-depth is as follows. Establish a line of section as near as may be at right-angles to the reef-outcrop. After carefully surveying all outcrops on or near the line of section, and recording their dips and strikes, the true horizontal distances between the reefs represented by the various points surveyed are obtained in the following manner.

Let A, B, C, etc., Fig. 1, be the observed points, with the strikes shown at each. In order to obtain the horizontal distance between the strata A and B, draw A O and B O through the points A and B at right-angles to the observed strikes. From O, where these normals intersect, describe with the radius O B a circle cutting O A at B'; then B' A is the horizontal distance between these strata. Similarly the horizontal distance between strata B and C is B C'. From B' lay off on the line of section B' C'', equal to B C'; and so proceed, referring to the line or plane of section all the observed strikes.

Having thus obtained the horizontal distances along the line of section between the points observed, the reef-curve is obtained as follows:

Along the horizontal line X Y, Fig. 2, lay off the points A, B, C, D, etc., according to the horizontal distances between these points in Fig. 1, and show the observed dips, *a*, *b*, *c*, *d*, etc. In order to find the thickness of rock between A and B,

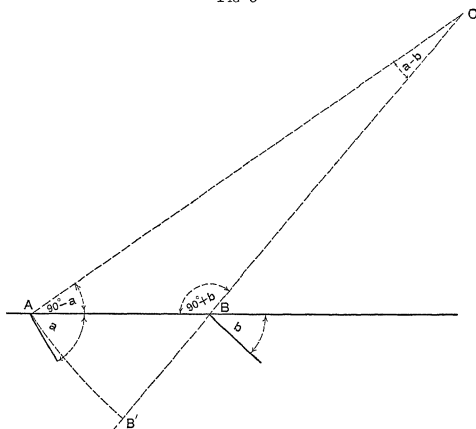
draw AO , BO , normal to the dips at A and B , and intersecting at O . With center O and radius OA , describe a circle



Diagram, Showing Method of Determining Horizontal
Distances between Reefs

cutting OB produced at B' ; then BB' represents the thickness of rock between A and B . Similarly CC' represents the thickness of rock between B and C . Thus the thickness of

FIG 3



Diagram, Showing Mr Hoist's Method of Calculating the Reef-Curve

“The distance A B (Fig 3) and the angles a and b , being given as data, angle $O A B = 90^\circ - a$; and angle $O B A = 90^\circ + b$, therefore angle $A O B = a - b$, and, since $O B' = O A$, it follows that $B B' = O A - O B$

$$\begin{aligned}
 &= \frac{A B \sin (90^\circ + b) - A B \sin (90^\circ - a)}{\sin (a - b)} \\
 &= \frac{A B}{\sin (a - b)} \times 2 \cos \left(\frac{180^\circ - a + b}{2} \right) \sin \left(\frac{a + b}{2} \right) \\
 &= \frac{2 A B \sin \left(\frac{a - b}{2} \right) \sin \left(\frac{a + b}{2} \right)}{2 \sin \left(\frac{a - b}{2} \right) \cos \left(\frac{a - b}{2} \right)} \\
 &= A B \frac{\sin \left(\frac{a + b}{2} \right)}{\cos \left(\frac{a - b}{2} \right)}
 \end{aligned}$$

“Or, graphically, from A lay off an angle $O A B' = \frac{180^\circ - a + b}{2}$, intersecting $O B'$ at B' , which it must do, since $O A B'$ is an isosceles triangle, with each angle at the base $= \frac{1}{2} [180^\circ - (a - b)] = \frac{180^\circ - a + b}{2}$,”

The diagram, Fig 4, shows a series of reef-curves traced by the above method. From such a diagram, the depth of reefs below any given point on the line of section can be estimated

In this diagram, the outcrops are as follows (the distance, in feet, of each outcrop from the main reef being given in parenthesis) .

a Main reef (0); *b* South reef (150); *c* sandstone (560), *d.* sandstone (1000), *e.* sandstone (1200), *f.* Livingstone reef series (1600 to 1700), *g.* sandstone (2160); *h.* Bird reef series (2900 to 3600); *i* sandstone (4180), *j* sandstone (5200); *k* sandstone (5700), *l.* Kimberley reef series (6300 to 7000), *m* sandstone (7260); *n* sandstone (8300); *o* sandstone (9500), *p.* sandstone (10,960); *q* sandstone (13,490), *r* sandstone (14,160), *s.* sandstone (16,060); *t.* sandstone (16,960)

Future Deep Mining.—In the writer's judgment, it would be premature to forecast at this time the ultimate depth to be reached by mining on the dip of the Witwatersrand reefs. It is interesting to note that shafts have been started already with a possible ultimate depth of 6000 ft., and the tenders invited for the permanent hoisting-engines to equip these shafts call for capacity to work from that depth. It is now pretty generally believed by engineers that the development of mechanical appliances for deep mining will keep pace with the requirements, hence the mechanical problems involved in mining at depths in excess of this figure may safely be left until mines working at 3000 to 4000 ft. in depth are paying dividends. Beyond this, it is certainly not necessary to go at present; for, although progress in the direction of deep mining upon the Rand has been startlingly rapid, it is still the logical result of underground development;—of the yield of gold and the profits obtained from deep-level mines now in the producing stage.

Public confidence in deep-level mining upon the Rand may be said to have been firmly established by the results obtained from the first and second row of deep-levels; and, if we now turn towards the 4000- to 6000-ft. deep-level areas in the confident hope of accomplishing similar results, certainly the development of still deeper areas is not likely to be undertaken for some years to come, or until the *crux* of the whole question, namely, the profitable character of the deposits, has been fairly well demonstrated at the depths first mentioned.

It is to this all-important point that such writers as Mr.

John Yates* give, perhaps, least attention—possibly, for the very good reason that nothing is known of it at the depths, such as 12,000 ft., of which he writes. Engineers who have to face the financial expenditures, as well as the mining problems involved in working at present depths, may be pardoned for feeling some surprise at the facility with which this writer figures the cost of sinking very deep shafts and inclines, and the exactitude with which he calculates the cost of different methods of deep hoisting, within differences of 5*d.* and 7*d.* per ton. That the working-costs of the first row of deep-level mines are greater than those of the outcrop-companies is now an established fact, as can be seen by anyone who chooses to consult the annual reports of the companies in question; and, although the shafts of the first row of deep-level mines average but 1189 ft. in depth, this difference of operating expense is measured, not in pence, but in shillings per ton. That it will be reduced in the future is certain, nevertheless, the decrease must be the result of time and improved conditions. Still deeper mining will be similarly affected, but it is yet too early to calculate with any accuracy the cost of hoisting or of any other mining work at such extreme depths.

As to the increase of rock-temperature with depth, the writer confesses that, although in charge of a number of deep-level shafts, he has never made experiments to determine this point, which he considers to be a theoretical bugbear, having little practical bearing upon the ultimate depth to which mining will be carried. In the thick body of sedimentary quartzitic sandstones enclosing the Witwatersrand reefs, it is reasonable to expect but a slight increase of rock-temperature at depths of 6000 to 8000 ft. from the surface. The increase of air-temperature will be due less to this cause than to the higher barometric pressure and atmospheric stagnation, and can unquestionably be largely reduced by proper ventilation. There are to-day shafts from 1000 to 2000 ft. deeper than those in which the temperature-observations were made, which determined for the Rand the oft-quoted increase of 1° F. per 203 ft. While the writer has no reason to question the accuracy of the methods

* "Mining on the Witwatersrand to 12,000 ft Deep" A paper read before the South African Association of Engineers, and reprinted in the *N. Y. Eng. and Min. Jour.*, Sept., 16, 1899, vol. lxxviii, pp. 332, 337

adopted to establish this figure, he believes that the observations were not extended over a sufficient area, that is, were not taken in a sufficient number of shafts along the Rand, or to the greatest possible depths obtainable, to command complete acceptance of the results, as factors in actual mining. It will be time enough to cross the heat-limit bridge when we get to it; and certainly the indications are that it is yet a long way off.

The chief limitations to very deep mining on the Rand will be first, possible poverty of the reefs in gold, secondly, a possible thinning out of the reefs themselves, which would be equivalent in effect to the first-mentioned cause, thirdly, the possibility of encountering great amounts of water.

Examinations of deep-level properties thus far do not indicate a decrease of gold-contents with depth. The deep levels opened hitherto are, as a rule, equal in value to the mines of the outcrop-companies opposite them. Sometimes the yield per ton is smaller than that of the outcrop-companies, and sometimes larger; but these differences are often due to the unequal amounts of waste sorted out in the two mines.

The possible general thinning-out of the reefs themselves, thereby decreasing the gold-contents for a given area, and increasing the cost of mining, is likewise not indicated by developments so far. While such a thinning-out has happened in one or two of the second row of deep-level mines, it was also the case in the early stages of development of the first row of deep-levels. With the great and unceasing energy usual on the Rand, development in these cases was pushed on, and showed the thinning of the reefs to be only local. In the majority of the first row of deep-levels, from 5 to 7 miles of exploration and development-work was accomplished, and several hundred thousand pounds were expended underground, before a single stamp was dropped—with the result that wide bodies of reef were encountered as well as thin ones, and an average grade of ore was obtained almost at the outset, and maintained month after month. There is no reason to doubt that the same policy applied to the second row of deep-levels will give similar results; and it is worthy of note that in the one or two instances alluded to, where thinning of the reef occurs, only a few thousand feet of development has as yet been accomplished.

The possibility of trouble from water is happily very remote.

In only one of the deep-level shafts, namely, in the East or "Connor" shaft of the Knights Deep property, has water become a very serious feature. This shaft is about 1220 feet deep, and from $\frac{3}{4}$ million to $1\frac{1}{4}$ million gallons of water per day have been pumped and hoisted from it during the past two years. When pumping-operations had to be stopped on account of the war, the water rose to within 200 feet of the shaft-collar, indicating that, thus far, only about that depth of country had been drained. This shaft, however, is such a startling exception to the general experience on the Rand that it may be considered as proving the rule that water will not prove a serious drawback to very deep mining.

Dimensions and Construction of Shafts.—In the early stages of deep-level shaft-sinking on the Rand the depths to the reef were comparatively small, and all sizes and dimensions of shafts will be found in the first row of deep-level mines. When deeper shafts had to be sunk, it became advisable to adopt a uniform size of shaft, if only for the sake of the advantage of ordering the same sizes of shaft-timbers from the timber-merchants. With this object in view, a meeting of the leading consulting engineers and general managers was held, the result of which was the adoption of the size of shaft and dimensions of timbers shown in Figs. 5, 6 and 7. The majority of the shafts started several years ago, and proportioned for depths of 2000 ft. and over, are five-compartment shafts containing four hoisting-compartments and one pump-and-ladder-way. The hoisting-compartments have varied from 4 by 6 to $4\frac{1}{2}$ by 6 ft., which came to be recognized as a bad proportion, hence in the new shafts they are made 5 by 6 ft., with a $6\frac{1}{2}$ by 6 ft. pump-and-ladder-way. The advantages of balanced hoisting and of two hoisting-engines for deep work are self-evident; and while the pump-and-ladder-way is larger than is required for the air- and water-mains (especially since electric pumping with stations 500 to 1000 feet apart has been almost universally adopted in these shafts), the additional space in this compartment is useful as permitting the installation of a separate cage for the handling of air- and water-mains, electric cables, pumps, and any general shaft-work, without interrupting the regular hoisting-work of the mine. Aside from this, the additional area of the shaft is a distinct aid in reducing the velocity of the air-currents, es-

Fig 5

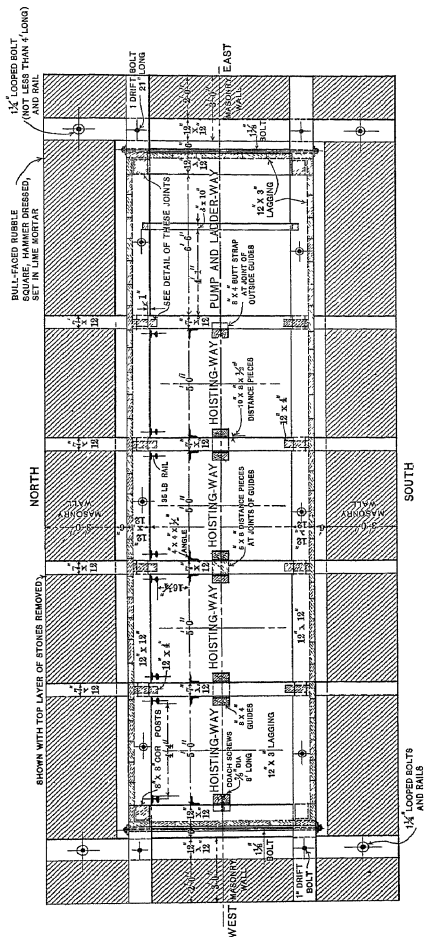
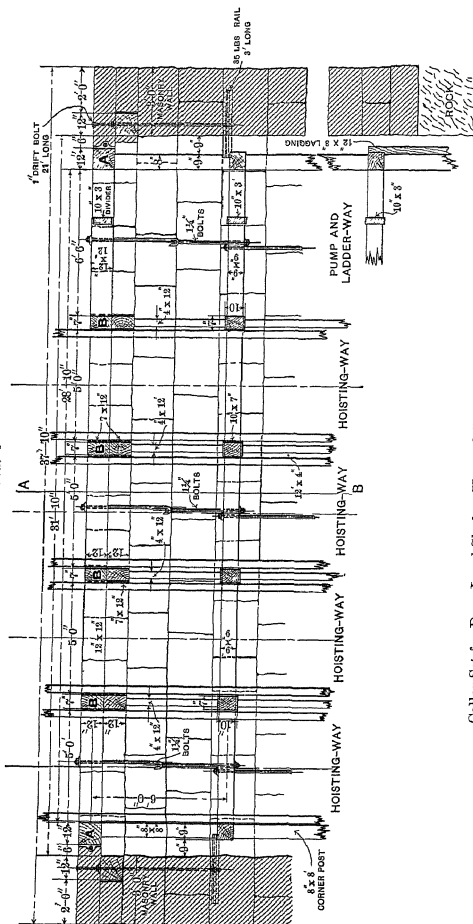


Fig. 6

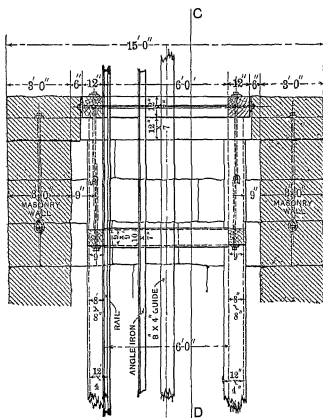


Collar-Set for Deep-Level Shaft Vertical Section through C—D, Fig. 7

pecially since the general adoption on the Rand of the writer's "combination" or joint shaft for a group of deep-level properties, described later in this paper, whereby fewer shafts, placed at greater distances apart than formerly, are used to work out a given area.

Fig 8 shows details of the end-plate and divider of the collar-set. The shaft-timbers are considerably lighter than the general practice in shafts of such size elsewhere. This is due to the fact that the quartzitic sandstone, through which the shafts are

FIG 7

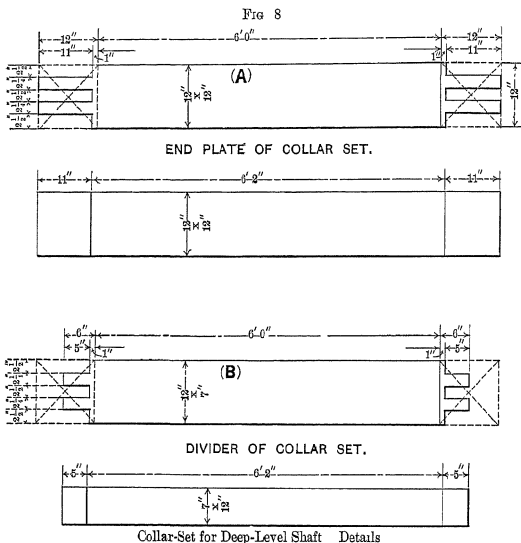


Collar-Shaft for Deep-Level Shaft Vertical Section through A—B, Fig. 6

sunk, is so hard and so compactly bedded that the walls of the shaft exert no pressure on the timbering, which serves merely to guide skips and cages through the shaft, and to sustain the lagging, where a dike, or a layer of more friable rock, is traversed. The studdles have, therefore, only sufficient size to support the wall-plates—than which they are 3 in. wider, in order more firmly to hold the dividers in place. The dividers are made an inch deeper than the wall-plate, in order to give a more secure hold on the studdles without cutting into the

wall-plate, while the guides have been increased in section from the usual 4 by 5 to 4 by 8 in.—additional stiffness, with sets 6 ft between centers, being considered desirable.

All these timber-dimensions are for what is known on the Rand as pitch-pine timber. In a few shafts the Australian *harri* wood, which is so strong that the amount of timber in each shaft-set is reduced by about 25 per cent., has been em-



ployed, but the extra cost of this timber makes it no cheaper than the pitch-pine, while it is much more liable to warp and more difficult to frame.

The masonry-wall around the collar of the shaft shown in Figs. 5, 6 and 7 is, so far as the writer is aware, an innovation upon the usual Rand practice. Along the Rand there is usually a surface-soil from 2 to 20 ft. deep; and heretofore it has been the practice to sink through this soil with a lagged shaft, the

collar-set being supported by extended wall-plates in the usual way. When it became necessary at a later period to erect the permanent head-works (a heavy structure, usually from 60 to 90 ft high), its foundations necessitated excavations to the bed-rock on all four sides of the shaft. These are always troublesome to make while work is going on in the shaft, and the foundations themselves require as much masonry as does this complete wall around it. By this method of building, at the outset, a masonry-wall around the shaft, from bed-rock to surface, the foundations for the permanent head-works are provided, while the inevitable decay of timbers imbedded in soil is avoided, and a more secure and lasting support for the collar-set is obtained.

Rate of Sinking.

The writer believes it perfectly safe to say that nowhere else in the world have vertical shafts, either larger or smaller in section than 25 by 6 ft., been sunk with such speed as upon the Rand. If this statement is incorrect, he trusts that some member will prove it to be so by bringing to the notice of the Institute a record of shaft-sinking exceeding that of the Howard shaft of the Simmer & Jack West, Ltd., namely, 203 ft. in one month—this being a 5-compartment shaft and 25 by 6 ft in size, inside of timbers.

There has been great competition in shaft-sinking upon the Rand during the past three years, and the record has passed rapidly from one controlling group to another, until now it is held by the Deep-Levels of the Consolidated Goldfields of South Africa, of which Mr R. M. Catlin is general manager, while Mr. Leslie Simson is the superintendent of the particular property mentioned.

The first shaft-sinking record was made by Mr. F. H. B. Cresswell, manager of the Durban Roodepoort Deep, who, in the month of September, 1896, sunk 135 ft. in a 4-compartment shaft. This shaft was sunk 726 ft in six months, at the end of which time it was 1410 ft deep; the monthly average being 121 ft. The next record was obtained by Mr. A. R. Robertson, manager of the Vogelstruis Deep, who, in December, 1896, sunk a 3-compartment shaft 141 ft., and timbered 147 ft at the same time. This sinking was done by machine air-drills. In July, 1897, the 5-compartment Clement shaft

of the Simmer & Jack East (now in the South Rose Deep) was sunk 156 ft. by hand-labor and timbered 147 ft., the total depth being 1546 ft at the end of the month. For the following month, August, the record was held by Mr. Sidney A. Chambers of the Angelo Deep, who sunk his 4-compartment West shaft 164 ft, timbering 150 ft., the depth of the shaft being 955 ft. at the end of the month. The drilling was done by hand and no machine-drills were used.

In shaft-sinking upon the Rand the men usually work three 8-hour shifts; and where hand-drilling is done, each shift is composed of one white miner and about thirty-five kaffirs

All the records above mentioned have been broken by the work accomplished by Mr R. M Catlin in the Howard deep-level shaft of the Consolidated Goldfields, in which he sunk in one month 203 ft, bringing the shaft to a total depth of about 2300 ft, which is the maximum record in point of depth at which the work was done, as well as in point of speed. The following statement of the work accomplished in the Consolidated Goldfields deep-level shafts will be of interest.

Shaft-Sinking of the Consolidated Goldfields Co

Shaft	Depth from Surface Feet	Average for 3 Months Feet	Average for 6 Months Feet	Average for 9 Months Feet	Average for 12 Months Feet
Milner	1,504	189 $\frac{1}{2}$	187		
Rudd	1,326	183	175		
Howard	1,767	182	168	152 $\frac{1}{2}$	146 $\frac{1}{2}$
Catlin	1,839	159 $\frac{3}{4}$	162	163 $\frac{1}{2}$	145 $\frac{1}{2}$

The timbering of these shafts is carried seldom, if ever, closer to the bottom than 50 ft, in order not only to avoid cutting the timbers by the blast, but also to give room for swinging the 28-ft. wall-plates without having to leave out too many of the dividers in the sets already in place. Often the timbering is from 100 to 150 ft. above the shaft-bottom, and the wonderful celerity with which the sets are put in place was remarked by Prof. Alexander Agassiz when he visited the Rand in February, 1899, and witnessed the operation. Most of the shaft-sinking is done by buckets through the two center compartments of the shaft, one bucket being filled at the bottom, while the loaded bucket is ascending and the empty

coming down, universal swivels being used to prevent undue rotation of the buckets.

In a few cases self-dumping sinking-skips are used, as in the Knight Central, where, under the writer's direction, the shaft was sunk to a depth of 2190 ft. Here, as a Whiting hoist was in use, the ordinary buckets proved too light in weight to keep proper tension upon the rope and prevent slipping on the drums. These vertical sinking-skips are, however, avoided wherever possible, because they require the timbering to be kept so close to the bottom as to render it liable to damage by blasting.

In regard to the above mentioned high speeds of shaft-sinking, it is hardly necessary to add that, in all of these shafts, little or no water has been encountered. The necessary removal of large amounts of water would be, of course, fatal to rapid work. Moreover, the maximum speed of sinking requires good breaking-ground—in this case regularly-bedded strata of the quartzitic sandstones of the district,—and not too hard to drill (in fact, rather softer than the usual run of this rock); while the organization of the work and the discipline from engine-driver to kaffir cleaner and helper must be as nearly perfect as possible, to obviate the unnecessary loss of a single minute, especially when changing shifts. It is under these conditions that the above high speeds have been obtained. In many shafts on the Rand the organization is as good, but the absence of the natural advantages of good ground and no water have hindered the attainment of these extraordinarily high rates of sinking.

Cost.—The cost of shaft-sinking has varied from £17 and £18 per ft. at the Vogelstruis Deep and Durban Roodepoort Deep to £22 4s at the Glen Deep, £24 9s. at the Jumpers Deep; £22 7s, £23 3s and £28 12s at the Summer and Jack East, and, where water has been encountered in great volume, as at the Connor shaft of the Knights Deep, already alluded to, the cost per foot has gone as high as £41 8s. Where rapid sinking is done, these costs per foot naturally decrease, the average of 183 ft. per month in the Howard shaft was done for about £16 per ft.

Shaft-sinking costs, like all other working-costs on the Rand, were being gradually reduced when the war began; but £22

per ft. may be taken as an average estimate of the cost for a shaft from 2000 to 3000 ft deep. This includes the cost of timbering and of all mining supplies, as well as hoisting-ropes, air-pipes, etc, together with a proportionate amount of the office- and general-management expenses. It includes also the cost of cutting the pump-stations, which heretofore have been located 500 to 600 ft. apart, and are cut large enough to accommodate two three-throw electrically driven geared pumps, with capacities varying from 3500 gallons to 8000 gallons of water per hour each. The usual size of these pumps is 5 by 8 in.; but four sets of $6\frac{1}{2}$ by 8 in pumps, equal to about 8000 gallons per hour each, are placed in a single station in the Connor shaft; and these have since been relayed by others.

Pumps and Power.—As the shafts in the first row of deep-level properties average but about 1200 ft in depth, Cornish pumps have been used in most of them, following the practice of the incline-shafts on the outcrop-mines. With the initiation of deeper mining in the second row of deep-levels came more modern practice; and in the great majority of these shafts the pumps are electrically driven, the stations being placed, as before said, 500 ft apart. The tendency now is to increase these distances, in order to reduce the number of pumping-stations in the very deep shafts now projected, so as to save the cost of cutting the stations and of maintaining so many pumps and motors. It is therefore highly probable that lifts of 1000 ft. will be adopted in the future.

At the 1200-ft. station (practically the bottom) of the Ferreira Deep, East shaft, there is a compound Riedler plunger-pump, driven by compressed air, which takes the water in a single lift to the surface. A specially-designed re-heater, burning coke, is used to re-heat the air before its use in the compound cylinders of this pump, and the fire is so small that the natural ventilation through the shaft, close to which the pump is placed, is all that is needed to carry away the products of combustion. This is the first instance of the use of compressed air in deep-level shafts for other than auxiliary pumps. The sudden advent of the war prevented the obtaining of data as to its efficiency.

In the pumping-plants of three of the deep-level properties under the writer's supervision, three-phase generators are used

of 100 k.w and 150 k w. capacity, carrying 950 volts between the outer wires. There has been no difficulty whatever in carrying this voltage down the shafts in properly insulated lead-covered armored cables.

The Consolidated Goldfields of South Africa has a large central pumping-plant consisting of three 500 k.w three-phase generators, built by the General Electric Co. of New York, and carrying 3000 volts, which is transformed at the shafts to 110 volts, before being carried down to the pumps.

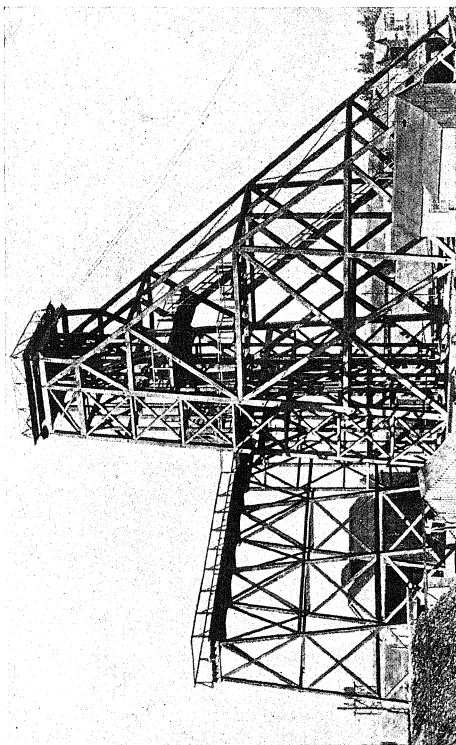
In the writer's opinion, electricity is superior to compressed air for pumping-purposes, while any surplus power of the plant (should the anticipated amount of water not be encountered) can be utilized in running hoists upon incline shafts and winzes underground in the mine, or in operating pumps in the cyanide plant, tools in the machine-shop, or in a variety of other ways upon the surface.

Skips—Returning to the description of the shaft-work itself. When a deep-level shaft is completed, the center-guides are taken out of the hoisting-compartments, and these are fitted with T-rails and angle-irons, as shown in Figs. 5 and 7, to guide the wheels of an ordinary iron skip. These skips weigh about $2\frac{1}{2}$ tons each, and carry 3 tons of ore. As the shafts go deeper on the Rand, this load will undoubtedly be increased to 5 or 6 tons; but thus far the practice is as stated.

Combination of Shaft with Incline Below—Most of the deep-level shafts of the first row have been turned upon the incline, and many of the shafts of the second row will unquestionably be so turned; hence I have shown in Fig. 9 the usual method of making and timbering this turn. Its advantages are numerous. It avoids the expense of a separate underground hoist, and enables development on the reef to proceed with the least possible delay. The skip runs from the incline into the vertical smoothly, and generally without any decrease in speed whatever, hence it is probable that its use will be continued in shafts up to 3000 ft. vertical depth. After that depth, in all probability, independent methods of hoisting on the incline will have to be adopted. At the same time, it is not at all certain that the use of the Whiting hoist will not permit the turning of vertical shafts upon the incline, even at this or greater depth.

The first Whiting hoist put in operation upon the Rand was erected under the writer's supervision at the West shaft of the Knight Central, Ltd.; and there are now four such hoisting-

FIG. 10.



Knight Central Head-Gear, West Shaft.

engines at as many shafts in this district, three of which were working up to the cessation of operations at the outbreak of the war.

Where shafts are turned upon the incline, the head-gears should be set upon the side of the shaft from which the turn is made, in order that the skips may dump on the free side of the shaft, away from the head-gear legs and the engine-house, and where there is more room for the necessary grizzlies, sorting-floors and bins. In the majority of instances on the Rand, this is the south side of the shaft, and most of the head-gears are so located.

Temporary and Permanent Head-Works—In order to start shaft-sinking without delay, temporary head-works from 40 to 45 feet high are usually erected, and are placed on the north side of the shaft, together with the small engines and temporary boilers. This equipment usually sinks the shaft for the first 700 to 800 ft., and has been known to go 200 or 300 ft. deeper. Meanwhile, the permanent head-gears, hoisting-engines and boilers are installed in their proper positions south of the shaft, where work can be carried on without interference with the shaft-sinking. The use of this temporary shaft-equipment, though expensive, pays in the end, as the ordering and delivery of the permanent equipment takes nearly a year, which time would be lost unless, as is very rarely the case, the formation of the deep-level company is known for that length of time in advance.

Most of the head-gears on the Rand have been built of timber, but the writer believes that the use of this material will soon be discontinued in favor of steel, which is much more durable, and but slightly more costly than timber.

The average height of the head-works of the second row of deep-level shafts is 85 ft. to the center of the sheaves. One of the better types is shown in the Knight Central head-gear, Fig. 10, designed and erected by Mr N. Wilson, mechanical engineer on the writer's staff.* The cost of this head-gear, erected, was £4200, including the temporary ore-bins and dump-trestle. As timber costs \$75 to \$85 per 1000 ft., B M., and the average carpenter's pay is \$5 per day, it will be readily understood how such high costs result. Similar head-gears, 75 ft high, have been erected upon the Witwatersrand Deep, Limited.* The

* SECRETARY'S NOTE—Detailed drawings of these structures, and of many other features of timbering, etc., on too large a scale for engraving, and yet too minute to permit reduction, are in the office of the Secretary, and may be consulted by those interested.—R W R

permanent ore-bins are built in front of the head-gears and the two sets of grizzlies, whereby a division of the ore into "fines," "mediums" and "coarse" is secured. The former usually go direct to the mill, while the two latter sizes are crushed and sorted in the crushing- and sorting-house.

A description of the ore-treatment does not come within the scope of the present paper.

II. METHOD OF WORKING THE GREATEST NUMBER OF DEEP-LEVEL MINES WITH THE FEWEST POSSIBLE SHAFTS.

Heretofore the general practice upon the Rand has been to sink upon each deep-level property two shafts placed, in the majority of instances, from 1600 to 1800 ft. apart, and connected by a drift as rapidly as possible after the reefs had been reached, in order to obtain ventilation.

This practice has been thoroughly warranted by the greater speed of underground development which it permitted, thereby bringing the property more promptly to a producing stage, and proving earlier, to the world at large, the value of the deep-levels. Though this distance between shafts has been, perhaps justly, criticised as too small, it must be remembered that it was inaugurated five and six years ago, and was even then an improvement upon the practice in the Lake Superior copper districts, where some of the shafts, especially in the deep-level ground, are astonishingly close, being in some instances only a few hundred feet apart.

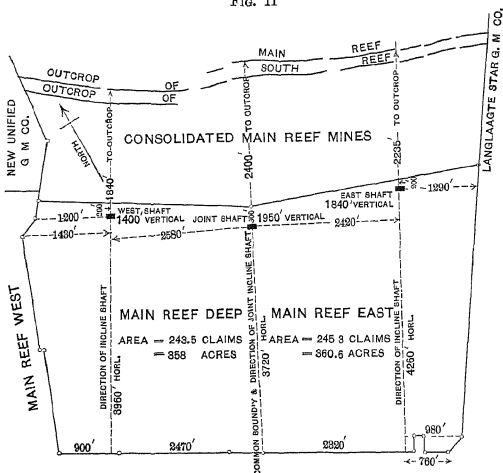
With deeper mining, however, the number of shafts employed to develop any given area becomes a most important matter, as the cost of sinking and equipping each shaft is a very large item.

Illustration for the Case of Two Properties.—The writer has, in consequence, adopted what may be termed a "combination" or joint shaft of the usual 5-compartment type, sunk upon the boundary-line between two adjoining deep-level properties at their common expense, by the use of which each company has to pay for $1\frac{1}{2}$ shafts in lieu of 2. This method was first put in practice in February, 1899, upon two deep-level properties under the writer's charge, namely, the Main Reef East and Main Reef Deep, belonging to the first row of deep-levels, and is shown in diagram, Fig. 11.

It has since been adopted in the Rand Victoria Mines, Ltd.,

and the Rand Victoria East, Ltd., of the Consolidated Goldfields of South Africa, the union shaft being placed upon the boundary-line common to these two properties (in the third row of deep-levels), while the Victoria shaft lies to the east in the Rand Victoria East property and the Albert shaft to the west in the Rand Victoria Mines property. It has also been adopted in a block of six deep-level properties, known as the

FIG. 11



Plan of the Main Reef Deep and the Main Reef East, Showing Location of Joint Shaft

City Deeps, under the control of Messrs H. Eckstein & Co., of Johannesburg (Messrs. Wernher, Beit & Co., of London). In fact the "joint-shaft" has come to stay, and will unquestionably be made use of in all future deep-level work

The cost of a shaft 2000 ft deep may be roughly estimated to be as follows

2000 ft sunk @ £22 per ft,	£44,000
Temporary equipment,	8,000
Permanent equipment,	40,000
Total,	£92,000

The sinking of a joint-shaft on the boundary-line will result in a direct saving to each company, in a shaft of 2000 ft. depth, of £46,000, while the subsequent shaft-maintenance and operating expenses will also be reduced by 25 per cent. from that of the two-shaft method

The writer's practice is to place the two flanking shafts from 2500 to 3000 ft. from the center or joint-shaft, according to the length of the property along the strike. While this position of the shafts increases the distances to be driven underground before connection can be made between any two of them, and good ventilation thereby secured, this is but a temporary disadvantage, which can and must be met by special arrangements for ventilating these drifts before connection is made. This difficulty has already been encountered upon the Rand, and in one case, that of the Crown Deep, where the shafts were only 1800 ft. apart, the drift from one shaft had to be advanced that entire distance before connection was made, by reason of faults and dikes which had dislocated the reef in the other shaft, and prevented the advance of a drift therefrom. It has therefore been demonstrated that a distance of 1800 ft. can be driven from one shaft alone, thereby allowing an actual distance between shafts on the surface of as much as 3600 ft., but this seems excessive, and need not be resorted to except in extreme cases. When, at the bottom of these vertical shafts, the inclines are carried down upon the reef, the same distance of 2500 to 3000 ft. will naturally exist between them, and may be considered too great for quick tramming along the levels. To obviate this, intermediate inclines may be put down, dividing this distance in two, and as an almost equally great distance will lie between the outer inclines and the boundaries (the average length of a deep-level property along the strike now being from 5000 to 6000 ft.), intermediate inclines will, in any event, be there rendered necessary.

In short, practice upon the Rand now tends towards fewer vertical shafts and more underground inclines, especially for the very deep mining about to be undertaken; and it is evident that this will result in a decided saving. Electricity or compressed air, preferably the former, can be used for operating these inclines, and, in the case of very deep mining, unquestionably the vertical shafts will be reduced to a minimum

by increasing the distances between them, as indicated, and by making three shafts serve four properties, as described later on.

The mine will be cut up into workable areas by means of independent inclines, sunk from a main double-track drift, connecting the vertical shafts, and operated by electric hoists, and since there is every probability that the dip of the reefs will decrease with distance from the outcrop, and will average nearer 20° than 30° , there is every likelihood that as these inclines get longer, they may be advantageously operated by means of mechanical haulage, thereby doing away with all underground hoisting-engines. Mechanical haulage may, and undoubtedly will, also be introduced in the double-track levels connecting the deep shafts.

It appears to the writer that by these methods all necessity for shafts of over 6000 ft. in depth will be avoided for a considerable number of years to come; certainly long enough to enable us to determine the various conditions outlined in the early part of this paper as affecting very deep mining.

It may be argued against the use of a joint shaft on the boundary-line common to two different properties, that to prevent friction in operation and to obtain harmony in the financial relationship, these properties must be under the control of the same parties or the same Board of Directors, so as to enable them to be put under the direction of one manager. It is true that one mining firm often controls two or more adjoining deep-level mines on the Rand, but this is not essential to the sinking of a joint shaft, as its supervision can be placed under the manager of either property, and the cost of its sinking and operation can be very readily kept separate, and has only to be divided by two every month in order to find the proportion chargeable to each company.

In this connection it may be well to say that the mining laws of the South African Republic are excellent. They are based upon the old Spanish mining law, the property being bounded on all sides by vertical planes; and they are exceptionally clearly defined—the result being that the mining-law expert is a minus quantity upon the Rand, and a lawsuit between mining companies is a thing almost unheard of in this district.

By this method of sinking three shafts to develop two properties, each company has six hoisting-compartments equipped

with three hoisting-engines, although in the early years of the development of the property only one large hoisting-engine will be required at each shaft, or $1\frac{1}{2}$ engines per property; the smaller geared engines used in sinking being employed in two of the compartments in each shaft while the upper levels are being worked.

It should be explained that the joint shaft must be sunk with the boundary-line dividing the shaft so that upon one side of it there are two hoisting-compartments, and upon the other side two hoisting-compartments and the pump-and-ladder-way; and the incline at its foot should be carried down following this boundary-line in the same way. In this way all the ore from one property goes into the two hoisting compartments sunk upon that property, and is dumped into the corresponding bins at the surface, after which it is easily kept separate.

Where, as is usually the case, the management of the two properties is under one control (and even where this does not obtain) joint mills may be erected for the treatment of the ore from both properties. Of such a method, resulting as it does in centralization of plant and reduction of running and maintenance-expenses, the advantages are obvious. It has already been adopted upon the Rand, and will, the writer believes, be still more generally used in the future.

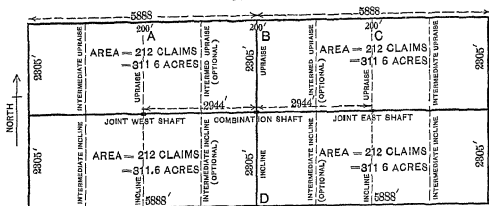
Illustration for an Assumed Case of Four Properties.—That this combination-shaft method can be further elaborated, with still greater saving to deep-level mining companies, is shown in diagram, Figs. 12 and 13, for an assumed group of four companies, the shafts being sunk upon the central boundary-line, so that each company has to pay three-quarters of the cost of sinking a single shaft.

Deep-level properties upon the Rand usually have from 200 to 225 claims in area, hence in the diagram an average area of 212 claims is assumed, giving a length along the strike of 5888 ft., and a horizontal distance, in the direction of the dip, of 2305 ft. This area is equivalent to a life of about 20 years with a mill of 200 stamps, these being the usual life and equipment of a deep-level property.

In the block of deep-level properties, known as the City Deeps, recently alluded to, the joint-shaft has been adopted, and the three shafts have been located by the consulting engi-

neer in charge at points corresponding to those marked A, B and C in Fig. 12; it being the intention, after sinking the

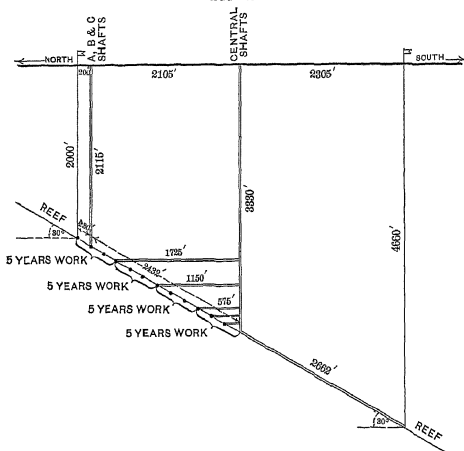
FIG. 12



Sketch-Plan of Four Deep-Level Properties

vertical shafts at these points, to push the inclines with all speed through the upper properties and into the lower ones,

FIG 13



Section through B-D, Fig. 12

in order to be able to begin development upon the latter without too much delay.

Let us now compare this method of shaft-location and development with the one proposed by the writer, of three shafts sunk upon the central or common boundary-line.

It is evident that shafts sunk upon the central boundary-line will be considerably deeper than those sunk in the usual position, 200 ft south of the north boundary of the properties. In order to ascertain how much deeper they will be, it is necessary to assume a dip of the reef.

This, as already stated, may be taken at 30° , and in the hypothetical case under discussion, the depth of the reef at the north boundary line is assumed to be 2000 ft. From these data we are able to construct the section shown in Fig 13, and obtain the depths of the vertical shafts and the lengths of the inclines required

It has already been explained that, in work upon the Rand, "time is of the essence of the contract," and in order to ascertain the relative merit of the two methods, it is necessary to assume a rate of vertical shaft-sinking, and a rate of incline shaft-sinking per month

From data already given, it will be noticed that a speed of 121 ft per month was attained in sinking vertical shafts over three years ago, while upon two shafts an average speed of 145 ft. per month has been maintained for a year, and much more than this has been accomplished for periods of three and four months. It seems perfectly safe, therefore, to assume a monthly average rate of vertical shaft-sinking of 120 ft., including the cutting of pump-stations.

For incline-shafts the data are much more meager, as these shafts are not pushed ahead in either the deep-level or the outcrop-properties, except as the development-work necessitates the opening up of say two or three levels every year. The highest speed on record is that of $165\frac{1}{2}$ ft., made in one month in the main incline-shaft of the New Primrose, an outcrop-property. These shafts have never been sunk with the same speed as has been attained in the vertical shafts, and for obvious reasons it is extremely doubtful whether, under the conditions under discussion, they could be. However, one may grant them the benefit of the doubt, and assume the same monthly progress of 120 ft. in the inclines

At this rate of speed, the centrally-located vertical shafts,

which are 3330 ft. in depth, will reach the reef in two years and four months. By means of cross-cuts, indicated on Fig. 13, which can be started before the reef is cut, development-work can be begun upon the two northern properties within two years and one month from starting these shafts, while development upon the two southern properties will begin three months later.

On the other hand, if the shafts were sunk at A, B and C, Fig. 12, the reef would be cut at 2115 ft. from the surface, or in 18 months from the time of starting to sink, and then development would begin upon the two northern properties.

At the estimated rate of speed it would, however, take 20 months longer to sink 2432 ft. of incline to the northern boundary of the two southern properties, and not even then could development-work be begun upon the latter—in fact, not until they had been connected by drifts—on account of the great difficulty of ventilating workings at the bottom of such long inclines. Assuming a speed of 125 ft per month in each of the headings at the bottom of these inclines, it would require a further 12 months to make these connections. The total length of time, therefore, which must pass before development-work could be undertaken upon the two south properties is about as follows:

Sinking vertical shaft 2115 ft , @ 120 ft per month ,	18 months.
Turning same upon the incline,	2 "
Sinking the incline 2432 ft , @ 120 ft. per month,	20 "
Drive connections 2944 ft , @ 250 ft per month,	12 "
Total,	52 "
or 4 years and 4 months.	

The comparison, therefore, stands as follows With shafts sunk at A, B and C, Fig. 12, development-work begins upon the two northern properties in 18 months after starting shaft-sinking, and upon the two southern properties in 4 years and 4 months; with shafts sunk on the common boundary-line, development-work begins upon the two northern properties in 2 years and 1 month after starting shaft-sinking, or only 7 months later than by the first method, while development-work begins upon the two south properties in 2 years and 4 months from the time of starting the shafts, or 2 years earlier than by the other method.

A similar great difference in cost can be shown, to say nothing of the fact that each company has to pay for only three-quarters of a shaft. While it may be argued that the number of shafts is not reduced, and hence the proportionate cost should be the same in both cases, it will be readily seen that such would not be the case, since shareholders in the two southern properties, having to wait $4\frac{1}{2}$ years before any valid development could be done upon their property, would naturally not feel disposed to bear the same proportion of shaft-sinking costs as the two northern companies, who reap the benefits of the shafts after $1\frac{1}{2}$ years from the date of starting them.

The new method is therefore more equitable in every way, and greatly simplifies the division of shaft-sinking and operating-costs, since, as development begins practically simultaneously on all four properties, each should bear one-quarter of these costs.

If it be argued that it is somewhat dangerous to start a cross-cut to the reef before the exact location of the same is known by the shaft piercing it, it can be shown that this is not a vital point, for the position of the reef is, in the majority of instances, known within 150 to 200 ft, and a variation of this amount need not affect the location of the first cross-cut, though it would, of course, lengthen or shorten it. In the latter case, other cross-cuts would be started higher up the shaft, in order to open out the necessary number of levels, if, on the other hand, the reef should be that much deeper, the additional distance would be so divided between the various levels lying between this cross-cut and the bottom of the shaft as to insure the ordinary "backs" of 175 to 200 ft. above each level.

While, of course, the first thing to be done after the shaft cuts the reef is to start the drifts to make connection between shafts, development-work upon all four properties need not wait for this connection to be made (as, in fact, it never has done so in any of the deep-level shafts sunk to date), since several hundred yards can be driven upon two or more levels before this connection is made without too great inconvenience through lack of ventilation. In fact, ventilation will be aided in the present instance by the system of cross-cuts to the north of each shaft.

While it is true that the two northern properties would have

to be opened up by cross-cuts which inevitably become longer as the age of the mine increases, it must also be borne in mind that the first three cross-cuts are comparatively short, and that number of levels will open up sufficient ground to enable the mill to be started, after which, only main cross-cuts, spaced five years apart, need be driven

In other words, these main cross-cuts may be so located as to divide the mine into four blocks, each of approximately five years' life (see Fig. 13), and only two long main cross-cuts need be driven to the shaft, as during the last five years of the mine's life connection for ventilation can be made with the mine above, the workings of which, in all probability, will have already closely approached its southern boundary. If it be argued that this will bring in the water from the upper mine, the answer is, that this water will inevitably drain through as the workings in the two mines approach each other, and cannot be avoided.

The work on each main cross-cut and on the incline connecting its terminus at the reef with the topmost level, five years below it, can be extended over several years; and the intermediate levels on the reef need not wait for its completion; as the incline can be driven upwards in the shape of an upraise, the stations cut and levels started a short distance each way, artificial ventilation being resorted to until the final connection is made with the long cross-cut, when the mine is blocked out for the next five years.

This method requires in the northern properties about 3900 ft. of cross-cuts at each shaft, costing, with ventilation appliances, shaft-stations and ore-bins, about £36,000, as against, in the southern properties, 2662 ft of incline at each shaft, costing with track and equipment, including intermediate pump-stations not required in the northern properties, almost £40,000 each, which inclines have to be maintained for their entire length up to the last year's life of the mine. The northern properties have no long inclines to maintain, and no underground hoists for such, other than small ones to run on the shorter inclines between the main cross-cuts, while the loading-stations in the vertical shaft need never exceed two in use at any one time. Again, the lift to the surface grows less and less as the mine is worked out, while mechanical haulage in the long cross-cuts will reduce tramping expenses to a minimum.

A comparison of the cost of the shafts required to reach the same point on the reef by these two methods will be somewhat as follows .

Shafts Sunk at A, B and C, Fig. 12.

2115 ft @ £22 per ft ,	£46,530
Turn in shaft,	3,500
2662 ft incline @ £15 per ft ,	39,930
Temporary and permanent equipment,	48,000
Total,	£137,960

Shafts Sunk on the Central Boundary-Line, Fig 12.

3330 ft @ £22 per ft ,	£73,260
Temporary and permanent equipment,	56,000
Total,	£129,260

This shows a saving of £8700 per shaft in favor of the newer method; though, were there no saving in cost, the advantage of the simultaneous development of all four properties would be quite sufficient to warrant its adoption.

In addition to the advantages already pointed out, shafts thus located are more satisfactory from a financial point of view, since the division of costs may be made upon the direct proportion of a quarter for each company. On the basis of cost of £130,000 for each of the three shafts, each company would have to pay three-quarters of this amount, or £92,500, equal to about three-eighths of what it would cost to sink the usual two shafts upon each property.

If, in order to work out the eastern and western ends of these mines, it should be found advisable later to sink additional shafts, by locating these at the extreme limits of the central boundary-line and making them serve four properties (as in the center or combination-shaft), the increased cost to each company would be but one-quarter of that of one shaft, or a final total of one shaft (say £130,000) per property.

If the underground workings in the adjoining properties to the east and west of this block of deep-levels should be carried on at the same rate, connections might be made between them, thereby securing ventilation and avoiding the necessity of the extra shafts. At the same time, the distance to drive in order to make such connections would be very great, and it is therefore highly probable that, later in the development of any such

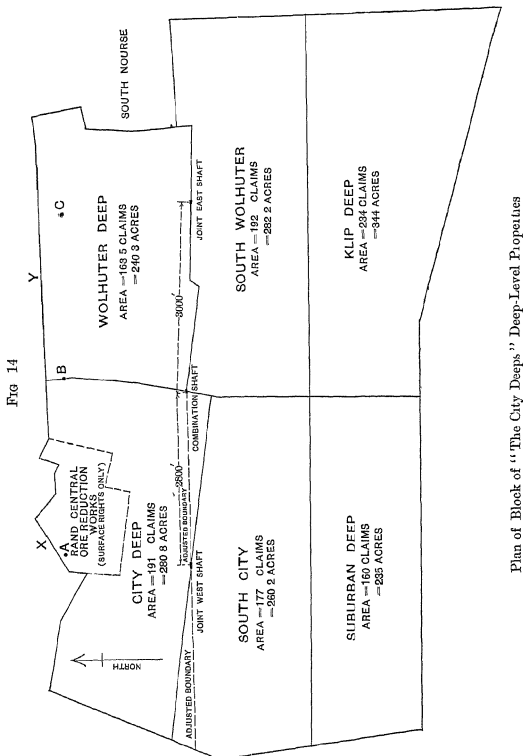
block of four deep-levels, it would be necessary to sink the additional shafts suggested. Such shafts could, however, be safely left until some years after the mine had reached the producing stage by means of the three shafts described, since to sink more at the outset would both very largely increase the initial expenditure and delay the period of production. It must be understood that in all deep-level work it is of vital importance to reach the producing stage as quickly as possible, and to keep the initial expenditure at as low a figure as may be consistent with the area to be developed and the scale upon which operations have to be conducted.

Fig. 14 shows the true shape and boundaries of the block of City Deep properties, with the approximate positions of the shafts, at A, B and C, as originally proposed by the engineers in charge, together with the positions as located by this new method, which, as shown in this diagram, would require a re-adjustment of one of the common boundary-lines.

This block is here mentioned, because it consists of six properties and not of four; and it might be assumed that three shafts could, in like manner, be made to serve for six properties by locating them in the center of the two middle ones. In the writer's opinion this, though perfectly feasible, would not by any means be accompanied by the same advantageous results. It is evident that the first work of development would be necessarily concentrated upon these two properties, while the other four would have to wait for several years before cross-cuts and inclines could be carried inside their boundaries, thus vitiating one of the main advantages of this method of shaft-location. The shafts should therefore be located on the boundary-line common to the four northern properties, and the two deepest properties should form a block with two more properties to the south of them, the shafts being similarly located.

While it is not the present intention to go fully into the question of the surface-equipment, in the way of stamp-mill and cyanide-plant, required by such a block of four properties, or to discuss the relative merits of the different-sized plants, yet it has been mentioned that each of the four properties has been assumed to be of sufficient area to supply a 200-stamp mill with ore for a period of 20 years; and upon this, the usual basis of a deep-level property, it is evident that these three

shafts might ultimately be called upon to furnish ore for 800 stamps. At the average stamp-duty of 5 tons per day, now obtaining on the Rand, this would amount to a daily crushing



of 4000 tons, or, allowing for the elimination of 20 per cent. of waste-rock, a daily output of 5000 tons, equal to about 1700 tons from each shaft. That three 5-compartment shafts will be ample to meet such requirements, including all handling of

men, tools, etc., is evident, when one considers what has already been done at the Kimberley diamond mines, where the record now stands as follows

"At the De Beers Mine on May 17, 1899, 9261 loads of blue ground, equal to 7409 tons of 2000 lbs each, were hoisted from a depth of 1200 ft by one engine (working in two compartments) in 24 hours""

Against the advantages of a single loading-station and shallower depth, possessed by the De Beers shaft, the proposed shafts, while of more than double the vertical depth, and containing several loading-stations, have an additional hoisting-compartment (assuming that one of their four hoisting-compartment be fitted with a man-cage only, as in the De Beers four-compartment shaft). Moreover, the maximum output of each of these 5-compartment shafts will be less than one-quarter of that of the De Beers

At the central shaft common to all four properties, some difficulty might be experienced in keeping separate the ore from each. Where ore belonging to two or more companies is hoisted through the same shaft, as in certain mines in the Michigan iron districts, it is a simple matter to keep each company's account separate, since iron-ore can be so readily sampled. This is not the case with gold-ores, especially those containing a certain proportion of free gold, as upon the Rand, hence, unless the companies combine, if not into one single concern, at least into two, composed each of a north and a south property, it must be admitted that both the underground and surface ore-bin arrangements may be somewhat complicated. This is a difficulty of detail which can be overcome, and which it is not necessary to discuss further here.

It suggests, however, the policy of a general pooling of interests in such a block of four companies, or their amalgamation into a single concern, but as this introduces financial questions, the writer does not care to go further into the matter at present, other than to point out that unquestionably the practical working of such a block of ground (of about two square miles in area) would be facilitated, and the engineering problem simplified, by such an amalgamation.

On the other hand, the adoption of joint shafts does not force such a combination, since it is evident that methods could be

* "11th Annual Report of the De Beers Consolidated Mines," p. 6

devised, enabling each company to work its ore for its own account, and obtain its own product therefrom in gold bars

Where "combination"-mills are employed, they are usually built of the back-to-back type. After the ore has passed over the plates, it lends itself to accurate sampling, since the free gold has been extracted, and hence the portions separately owned need not necessarily be kept separate in the subsequent cyanide-treatment. A combination of companies in pairs, each pair consisting of a north and south property, would mean eventually about 400 stamps in each mill, although each group could start operations with one-half that number, and increase gradually to the ultimate capacity as underground development advanced. In fact, this is the plan now generally adopted in all deep-level work on the Rand.

At present the largest number of stamps under one roof on the Rand is in the Simmer & Jack mill of 280 stamps. Preparations were recently under way to increase this number to 320.

The Iron-Mines of Hartville, Wyoming.

BY H M CHANCE, PHILADELPHIA, PA

(Canadian Meeting, August, 1900)

THE iron-ore deposits of the Hartville district are located near the new town of Guernsey, about 100 miles north of Cheyenne. The writer has been familiar with them since 1887, having visited the district several times for different clients—his last examination having been made in November and December, 1897.

The deposits extend in a general N.E.—S.W. direction from a point in Section 33, Range 65 W., Township 28 N., on the west side of Whalen cañon, through Sections 4, 5, 6, 7 and 8 of Township 27 N. in the same Range, and over into Sections 1 and 12 of Township 27 N, Range 66 W.

GENERAL CHARACTERISTICS.

The ore is a remarkably pure red hematite, extremely low in phosphorus, and carrying a small percentage of silica, as shown by analyses given below, and similar in many respects

to the red ore-deposits of Michigan and Wisconsin, occurring like them in lenticular bodies of extraordinary thickness, enclosed in a slate formation.

Four large bodies of this character have been developed by shafts, drifts and open-cuts, and it is probable that a number of similar ore bodies exist within these limits and will be developed from time to time as mining progresses. These lenticular bodies may be considered either as isolated masses of ore or as enlargements occurring at intervals along the course of veins of moderate thickness. Nearly all ore-deposits of this character may be so described; and I believe the developments here indicate that these large bodies of ore are enlargements of veins which extend as unbroken sheets of ore for considerable distances. While the developments are not sufficient to permit an estimate of the quantity of ore available within these limits, sufficient development-work has been done to place practically in sight, ready for mining, a very large quantity of high-grade material, so that a large output of high-grade ore can be maintained unquestionably for many years. This statement includes only ore averaging 62 per cent. or more of metallic iron. In addition to the large quantity of this high-grade ore which can be relied upon without including the possibilities of future discoveries in the district, there is also available an equal quantity of what may be termed medium-grade ore, that is, ore ranging from 52 or 53 to 60 per cent. of metallic iron.

Besides the known ore-bodies, there are numerous indications of the existence of others of similar character. Most of the district is covered by a nearly horizontal capping of sandstone or quartzite, 100 to 200 ft. thick, which lies upon the upturned edges of the older slates in which the ore-deposits occur, and it is only in the gulches and cañons, where erosion has cut away and removed this cap-rock, exposing the underlying slate formation, that the ore-bodies can be seen. Future development will doubtless show that they extend along the trend of the formation, beneath this cap-rock, far beyond the points at which they may now be seen, and the deposits so hidden may prove as large and valuable as those upon which existing developments have been made.

In addition to the lenticular ore-bodies the district contains deposits of another class, which I term secondary or re-

placement-deposits, occurring above the slates, in or near the base of the cap-rock, and sometimes connected with replacement-deposits in partially disintegrated siliceous limestone. The accompanying map shows a large number of drifts and shafts opened in the sides of the hills at this horizon, usually at an elevation of from 50 to 150 ft above the valley. These deposits or veins show a slightly inclined or horizontal stratification. They exhibit peculiarities, plainly indicating that the ore which they contain has been derived from the erosion of the lenticular deposits; in other words, this ore is probably debris from the ore-veins and ore-bodies occurring in the adjacent slates, and was deposited in nearly horizontal layers upon the upturned edges of the slates, or in the siliceous cap-rock, during the deposition of the latter. Scores of openings show deposits of this class. Many of them contain, or consist principally of, water-worn rounded boulders of ore, cemented together by a ferruginous or siliceous matrix. As a source of ore-supply these deposits are possibly of small value. But their great extent and their wide distribution over a large area clearly indicate that the ore-bodies from which they derive their material, and which are probably now hidden under the cap-rock, are large and possibly numerous.

In the immediate vicinity of the large ore-bodies exposed in the cañons more modern deposits of a similar nature can be seen at a number of points, and some of these, owing to the fact that the ore-nodules or boulders of which they consist are not cemented together, may be worked to advantage, and will yield considerable quantities of high-grade ore in the form of boulders or pebbles.

A description of these numerous prospect-holes, most of which were sunk by prospectors searching for copper, will be given further on.

Quality of the Ores —The hard red ore, locally called "blue ore," is almost invariably richer than the soft ore; but there is also much high-grade soft ore.

An average of 17 analyses of ores from this district, all made from samples taken by disinterested experts, shows, for the hard blue lump-ores: iron, 66.13; silica, 2.90, phosphorus, 0.038 per cent. Three samples of the soft red ore gave iron, 59.99; silica, 8.92; phosphorus, 0.010 per cent.

My own samples were slightly better than these averages, al-

though I was particularly careful to get an average sample of each grade of ore, by taking a quantity at random from many different points on the dump.

These samples were mainly from the openings in Sunrise Park. Two of them, however, were from the Chicago (Happy Thought) openings; and these showed for the hard and soft ore

<i>Chicago Ore.</i>			
		Hard Ore Per cent	Soft Ore Per cent
Iron,	. . . . .	62 35	58 75
Silica,	. . . . .	9.12	11 86
Phosphorus,	. . . . .	Trace	Trace.

The smelter-returns from over 5000 tons of ore shipped from the Good Fortune deposit during July, August, September and October, 1897, embracing 36 different returns of average analyses, show iron, 62 4, silica, 6.4 per cent.

It should be explained that this ore was mined in an open-cut, and that, in blasting, a considerable quantity of the hanging-wall was continually being knocked down, and became mixed with the ore. Moreover, the ore was hauled in wagons, and part of it was frequently unloaded on bare ground and then reloaded, more or less gravel and dirt becoming mixed with it in this way. If carefully mined and loaded into railroad-cars at the mine, this ore would certainly have averaged 65 or 66 per cent. of iron, with not over 3 to 4 per cent. of silica. As shipped, it is mainly of the harder variety, but contains a little soft ore.

It is safe to say that the total output of hard ore can be relied upon to average 64 per cent. of metallic iron, and that the silica will not exceed 3 5 per cent. The soft ore will range from 58 to 62 per cent., averaging say 60 per cent. in iron, with about 8 per cent. of silica; and, with care in mining, the silica in the soft ore can probably be kept down to 6 per cent.

If about equal quantities of the hard and soft ore be mined, a product of about the following grade can be obtained: iron, 62.00 or more; silica, 5.00 or less, phosphorus, 0.04 or less, per cent.

In the above statement it has been intended to indicate the grades of ore that can be relied upon absolutely in thousand ton lots to yield not less than the percentages named. The actual results will probably be better than these figures, by a very considerable margin.

THE ORE-BODIES.

The four great ore-bodies opened in the Hartville district are located as follows (1) The Sunrise ore-body, and (2) The Village Belle-Lone Jack ore-body, in Sunrise Park, (3) The Good Fortune ore-body, $\frac{3}{4}$ mile east, and (4) The Chicago (Happy Thought) ore-body, $1\frac{1}{2}$ mile northeast of Sunrise Park.

The Sunrise deposit has been opened to a depth of 110 ft in search of copper, showing it to be about 100 ft. thick and to extend laterally along the trend of the formation at least 900 to 1000 ft. Dr. Ricketts, as Territorial Geologist, estimated that this deposit would yield 750,000 tons for every 85 ft. in depth on the deposit. The vein is inclined at a high angle, and doubtless extends to great depth.

The Village Belle-Lone Jack ore-body is opened at several places for a distance of about 800 ft. The developments were made in search of copper, and do not clearly show the thickness of the deposit, but indicate that it ranges from 15 up to possibly 50 ft or more in thickness. It doubtless extends into the hills far beyond the last opening made upon it. It has been developed to a depth of 50 to 70 ft by a number of shafts, all of which struck high-grade iron-ore.

The length of the Good Fortune ore-body is not known, but the surface-indications warrant the belief that it is several hundred feet long. It has been developed by the workings of the Good Fortune mine for about 100 ft. in length and about 60 in depth, showing a maximum thickness of about 30 ft., of which over 20 ft. is high-grade ore.

The developments on the Chicago ore-body are sufficient to prove the existence of a large deposit, and indicate a thickness of perhaps 50 ft. or more, and a lateral extent of several hundred feet; but the prospecting was not intelligently directed, and while a large amount of work was done, it was not done in a way to show precisely either the thickness or extent of the ore-body. It is clearly a large and important one.

In addition to these four great ore-bodies, there are others which have been partially opened, and there are three localities in which large ore-bodies probably exist, but in which the ore can only be reached by boring or by shafts 150 to 250 ft. deep. An expenditure of a few thousand dollars at these places will probably result in the development of deposits containing millions of tons of ore. Many thousands of dollars have already

been spent in this district in the prosecution of poorly planned work, which could not be expected to develop large bodies of good ore, but this was largely due to the fact that most of this work was done in search for copper deposits

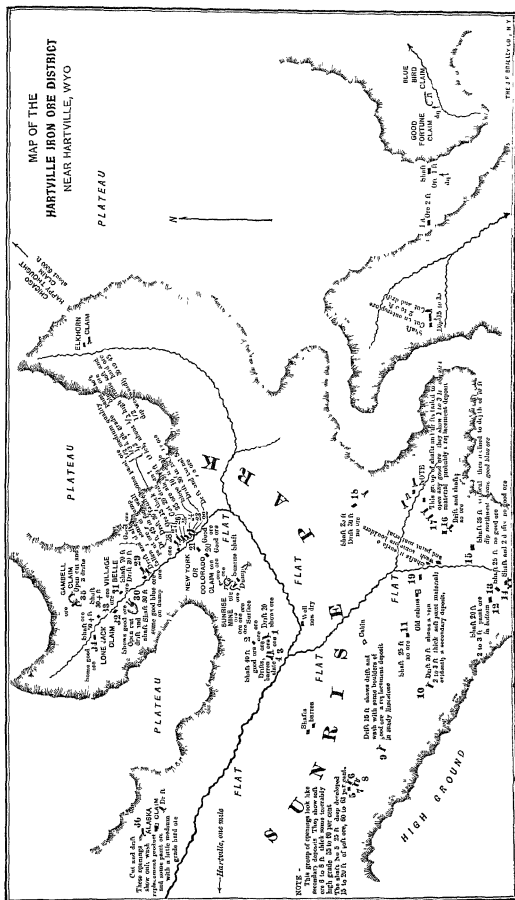
DETAILED DESCRIPTION OF OPENINGS.

In following this description of the various openings in the Hartville district, as they existed in February, 1898, reference may be had to the accompanying map, upon which they are designated by numbers. I could not in every case determine upon what claim the opening was located, the boundaries of the various claims not always being easily found in the neighborhood of the openings. For the same reason no attempt has been made to show on this map the boundary lines of the various claims. The location of the various openings with reference to each other is sufficiently accurate for all practical purposes.

No. 1 is a drift, about 500 ft. S W. from the Sunrise mine, and located upon the Sunrise deposit. It has been driven in a distance of about 20 ft and shows 8 or 10 ft of ore-material, containing some very high-grade ore. Between this and No. 2, a distance of 100 to 120 ft, the ground is covered with ore-material of excellent quality—the soil is an ore-soil. It is evidently the outcropping of a large body of ore. The surface showing at this point is even better than that nearer the dump of the Sunrise mine.

No. 2 is a shaft, about 40 ft deep, located near the upper or north-western edge of the ore-body. The dump shows a considerable quantity of siliceous material, but there is also a large quantity of fine bluish ore of excellent quality at this point.

The ore-ground here seems to terminate abruptly to the south-west, and barren slate shows in the shaft or drift at openings Nos. 3 and 4. The theory has been that the ore-body here turns and crosses the gulch, this being the most plausible explanation of the barren ground at openings Nos. 3 and 4. The soil from this point downward towards the gulch is all red and full of boulders of ore. No ore shows on the other side of the gulch, and some holes which were sunk on the flat failed to strike ore. The continuance of the red soil down towards the gulch is easily accounted for by the tendency of all soils to move down hill, and it will not be safe to assume this ore-body extends across the gulch. It seems most probable that near this



point the large ore-body diminishes in size to a vein of moderate thickness, and this continues across the gulch

Nos. 3 and 4 are drifts in barren slate.

The openings thus far described are near the south-western boundaries of the Sunrise claim, or possibly across the line on the General Sherman claim

Nos. 5, 6, 7 and 8 constitute a group of openings comprising a shaft about 30 ft. deep, two drifts 15 and 20 ft. long, and an open-cut of about 15 ft., which appear to have been made in search of the continuation of the Sunrise vein. They show 6 or 8 ft. of what is locally termed "Paint" ore, a term which I here use to describe an extremely soft unctuous red hematite, containing anywhere from 45 to 65 per cent. of metallic iron, and carrying impurities which are apparently free from grit, in most cases consisting largely of alumina, the percentage of silica being low. Some of these "Paint" ores are good iron-ores, especially those ranging from 50 to 60 per cent. in metallic iron. This group of openings shows some high-grade material, but most of the material is rather low in grade. The deposit dips about 60° N. In the shaft, 15 to 20 ft. of high-grade soft ore was passed through. Mr. McCreath's analyses from my samples showed 63 to 65 per cent metallic iron. I think it more than probable that these openings are located on the outcrop of a vein which further development may prove to carry a large body of workable ore, and if followed along its trend may widen out into one or more additional large bodies. It is probable that this vein is the south-western extension of the Sunrise deposit

No. 9 is a drift about 15 ft. long, showing lean surface-wash loaded with red iron, and containing some small boulders of good ore. It appears to be a secondary or replacement-deposit in a sandy limerock.

No. 10 is a drift about 30 ft. long, showing a vein of 2 or 3 ft. of soft paint-material, evidently a secondary deposit.

No. 15 is a shaft, about 70 ft. deep, which for the first 35 ft. was sunk vertical through lean ore and barren material. At that depth a vein of high-grade, good-looking bluish ore was struck, which will average from 60 to 62 per cent. in metallic iron, and the shaft was continued on an incline following the dip of the vein to a depth of 70 ft. It is asserted that 4 or 5 ft in thickness of this quality of ore was followed all the way from

35 to 70 ft. in depth, and I have no doubt this statement is substantially correct

This is in all probability the westward extension of the vein now worked at the Good Fortune mine, about 3000 ft. across the divide westward from this point

No 17 is a group of 7 or 8 pits, cuts, drifts and shafts, none of which show any workable ore-bodies, although, in two or three of them, from 1 to 2 ft. in thickness of very fair-looking ore is exposed, and some of the cuts show boulders of good ore. It seems probable that most of these boulders have been derived from the outcrop of the vein struck in shaft No 15. A small vein apparently passes through these openings; and it is possible that this vein, and not the one opened at shaft No 15, is the westward extension of the Good Fortune vein

About 1500 ft almost due east from the No. 17 group, and across the divide, are three openings, a shaft, an open-cut or trench, and an open-cut and drift, all located immediately upon the outcrop of a vein of ore which I believe to be an extension of the Good Fortune vein. They show the vein of ore in variable thickness, the good ore ranging from 2 to 5 ft thick, and dipping from 15° to 35° N. Some of the ore is of excellent quality, but about one-third of it contains large fragments of quartz and quartz crystals and is practically worthless.

Continuing 700 ft. east across the gulch we find another pit evidently located on the same vein and showing about 2 ft. of ore. The rocks here are apparently limestone or lime shale. About 350 ft. further east is another pit about 10 ft. deep, located immediately at the summit of the divide. It shows from 6 to 8 ft. of ore-material, of which about 4 ft. is ore of good quality.

This pit is only a short distance from the Good Fortune mine. No openings have been made between it and the mine-workings, but the continuity of the vein is established by boulders of ore which can be seen at many points along the side of the hill

No. 20 is a shaft, about 300 ft. N.E. from the Sunrise mine, and located immediately upon the Sunrise body. It passed through some 15 ft. of lean material, striking some good ore at the bottom.

No. 21 is a shaft but a short distance from No 20. It was located upon what was originally called the New York claim,

but is now known as the Colorado claim. After passing through 10 ft. of lean material on the surface, this shaft continued down to the bottom, a depth of 22 ft., in ore of superb quality. There is no difficulty whatever in selecting from the dump at this point ore which will run all the way from 65 to nearly 70 per cent. in metallic iron, and I do not think there would be any difficulty in shipping ore from this point that would average 66 or 67 per cent. in metallic iron in car-load lots. I have never seen handsomer ore.

I believe it has been generally assumed by a number of experts who have examined this property that the Sunrise ore-deposit or vein extends N E. across the gulch, beyond shaft No. 21, into the opposite hillside, and under the plateau to the north-east. Unless there be an offset in the deposit at or near the center of the gulch, or a fault deflecting it to the south, this theory must be abandoned, for the openings, Nos. 22 to 28 inclusive, located immediately on the trend of the deposit, plainly show that the vein does not pass into the hill at this point. I do not think it a matter of any importance whether the vein be deflected at this point, whether it be broken by a fault, or whether it terminates from some other cause. Should these ore-deposits be found to be enlargements of a continuous vein of moderate size or, on the other hand, disconnected lenticular masses of ore, the result will be the same. The cost of mining would be no greater under one set of conditions than under the other, and the future yield of the deposits will be a function of their size, and will not be affected by the question whether they are connected by thin sheets of ore or not.

No. 25 is a drift of 25 ft and an open-cut of about 20 ft. In this drift, driven obliquely across the trend of the rocks, a vein of ore about 9 ft. thick was cut across from the foot- to the hanging-wall. Of this 9 ft., about one-half is high-grade soft ore, and about one-half high-grade harder, bluish ore. The deposit dips about 30° to 45° W. This opening is directly in line with the Sunrise and New York or Colorado shafts, and only about 100 ft. from the latter. The vein of ore shown in this opening is, however, dipping westward, and its course is nearly at right angles to that of the Sunrise deposit. If this is the Sunrise ore-vein, then it seems certain that the deposit is here deflected at nearly a right angle, and if this be

true, the ore-bodies developed up the gulch to the north-west at openings No 29 to 34, including the Village Belle and Lone Jack claims, are all located upon this deposit

No 26. This drift shows about the same conditions as those described at No 25, except that the ore is here about 15 ft. thick, consisting one-third of medium quality, one-third of high-grade soft material, and one-third of hard bluish ore of fine quality. The vein, as exposed by these two openings located within a few feet of each other, is certainly trending northwest

No 29 is a group of a shaft and two drifts. The shaft shows some good blue ore on the dump. The drifts are fallen in and cannot be examined, but the material on the dump shows very little ore—mainly paint-ore.

No. 30 is a large open-cut and drift, with a shaft sunk inside the drift or cut. The inside work was somewhat fallen in. There was quite a good showing of good blue ore here on the dump, but also much siliceous matter and low-grade ore. The formation here is too much broken and jumbled or faulted to permit determination of the thickness of the ore

No. 31 is the famous Village Belle shaft, which had been sunk 70 ft when water stopped the contractors from sinking further. It is said that the shaft passed through 30 ft of good ore, and that a drift 30 ft long was driven from the bottom. The dump shows some hard bluish ore of most excellent quality, and it is said that a very much larger quantity of high-grade ore exists in the dump than that which can be seen at present, having been covered by poor or barren material taken out of the drift after the ore was extracted.

No. 32 is a shaft 50 ft., or more, deep. About three-fifths of the material taken out was rock and lean ore. The balance was bluish ore of the finest quality. The showing here is one of the best to be seen in the district

No. 33 is a shaft 20-odd ft. deep, sunk in the flat. It passed through about 10 ft of loose wash, then through 10 ft or more of fair paint-material, with some hard bluish ore of good quality.

No. 34 is a shaft very similar to No. 32. It is 50 ft. or more deep, with water in the bottom. About three-fifths of the material on the dump is paint-ore of medium grade, the balance being very high-grade soft ore, with a small quantity of harder

bluish ore. This is also a very good showing, but not quite equal to that at No. 32.

No. 35 comprises an open-cut or stripping and two drifts, located on Mr. A. B. Gambell's claim. They show a well-defined vein of hard bluish ore, 10 ft or more in thickness, and dipping about 30° to 35° S. to S.E. Some of this ore is of very high grade, some of it somewhat siliceous. The developments are not sufficient to determine the full value of the deposit at this point, but the indications are that the property will develop into a valuable mine.

No. 36, located about 2000 ft. N.W. of the Sunrise mine and on what is known as the Alaska claim, comprises an open-cut, and a drift driven in from the open-cut, all the openings being at a considerable elevation above the gulch, and near the base of the cap-rock. A considerable quantity of loose and cemented ore-boulders, with some paint-ore, have been exposed. Limestone outcrops near by; and the deposit gives every evidence of being one of the secondary or replacement-deposits, to which reference has already been made.

The Nightingale Claim.

About one-half mile N W from No. 36 (just beyond the limits of the map) is the Nightingale claim. It consists of a drift into the hillside about 40 ft. long, and high up on the hill. Limestone appears in the hill below the ore, with sandstone at the level of the ore openings. The dip is apparently 30° W. There is here apparently about 8 to 12 ft of ore, a little being of fair quality, but most of it looking like 30-per-cent. stuff. It is exceedingly doubtful whether this is the outcrop of a vein or not. It looks very much like a replacement deposit. Besides the drift, there is a shaft near by, about 40 ft. deep, which passed through some good ore. There are about 4 tons of 62 per cent. ore on the dump.

About 400 ft. in a northerly direction from the Nightingale openings is another drift, located upon the Vaughn and Covington claims, which shows about 6 ft. of ore material, carrying some lumps of very good ore. The deposit here dips about 30° W., and is evidently a secondary deposit of the same general character as that exposed at the Nightingale openings. The ore-material shades off into rock in both directions, plainly

showing that it is a replacement-deposit, reinforcing the conclusion reached respecting the Nightingale deposit, and indicating the probability of the existence of a large vein or deposit in the vicinity of these openings.

One mile to the south-east of Hartville a number of openings may be seen from the road leading from Hartville or Fairbanks across the divide into the Whalen cañon country. Some of these claims are known as the Shaw and Somers openings. They show siliceous paint-material, but no marketable ore. The openings are in limestone, at the junction of the lime and sandstone or quartzite formation, and they evidently expose secondary or replacement-deposits, similar to those described in Sunrise Park at a number of points. It is possible that at greater depth these may develop into ore-bodies, but such an assumption cannot be made with safety. I examined about 8 openings in this neighborhood, of which 3 show some lean siliceous ore; but the rest were in barren rock. As already stated, the existence of secondary or replacement-deposits of this nature is a strong indication of the existence in the vicinity of the true veins or deposits of ore of considerable size; for it seems certain that the boulders of ore which are found in all openings of this class were derived from true ore-veins or deposits, and as some of them are more or less angular, it is not probable that they have been transported far from the source from which they were derived.

The Good Fortune Mine.

The deposit exposed by the workings of the Good Fortune mine, when visited early in November, 1897, showed a thickness of perhaps 30 ft. of ore. It is impossible to measure the thickness of the ore-body accurately, as the dip of both walls is variable, and two persons making such measurements would not be likely to adopt the same point from which to measure, or to make their measurements at the same angle to the horizon. It can, therefore, only be stated that the maximum thickness of this ore-body, as shown by the workings at the time of examination, was in the neighborhood of 30 ft. The ore-body has been developed 100 ft. east and west along the trend of the vein. The vein dips northward from 30° to 60°, or about an average of 40° to 45°, at the surface, and the ore chute appears

to be pitching toward the east, at about 30° on the plane of the ore-body

At the east end of the open-cut an incline has been sunk about 60 ft. on the vein. The hanging-wall is here much steeper than in the open-cut nearer the surface. Both walls are well defined. Going both to the east and west from the point in the open-cut where the ore shows its maximum thickness, the vein seems to pinch down to a much smaller size. Not all of the ore in the vein is high-grade ore. Near the west end of the open-cut there is a maximum of about 15 to 20 ft. of high-grade ore; at the east end this high-grade ore pinches down, I believe, to 6 or 8 ft. in thickness. It is on this good material that the incline has been sunk. There was some excellent ore in the bottom of the incline, and in a drift and cross-cut which had just been started from the bottom, about 45 ft. vertically below the floor of the open-cut.

Average Quality of Good Fortune Ore.—This ore makes an excellent smelter-flux, and in the winter of 1897-98 was shipped to the Colorado smelters for this purpose. The average returns of smelter-analyses on shipments of over 5000 tons made during July, August, September and October show 62.4 per cent. of metallic iron and 6.4 per cent. of silica. Careful mining would bring the iron to 64 or 65 per cent. and the silica down to 4 per cent.

The Blue-Bird Claim.

This claim adjoins the Good Fortune claim, the Good Fortune mine being located but a short distance from the Blue-Bird boundary-line. The indications all strongly point to the conclusion that the ore-vein opened in the Good Fortune mine continues east through the Blue-Bird and, crossing the gulch, extends under the flat (prairie), passing close to the cabin occupied by Mr. Somers. The developments are not sufficient to show either the thickness or the character of the ore-vein or ore-chutes upon this claim, but the surface-indications, the boulders, lumps and pebbles of good ore which may be found scattered in the soil and lying upon the surface for a long distance, indicate plainly that the vein is one of considerable extent.

The Chicago (Happy Thought) Openings.

About two miles N. E. of the Sunrise mine, and about the same distance from the Good Fortune, a number of openings

have been made upon a large and rich deposit of ore, similar in every respect to the Sunrise deposit. They are located in a cañon tributary to Whalen cañon, and about three-quarters of a mile west from the center of the latter, from which they are easily accessible. One of these is a shaft 50 ft. or more deep, sunk most of this distance through ore. About one-third of the material taken out was ore of good quality, some being of very high grade, the rest was barren material and paint-ore.

About 75 ft further north there are two drifts and one shaft, all connected, which show 6 ft of hard bluish ore of good quality, and 10 ft. of paint-material of fair quality. The dip is 60° E. At another point in these openings the measurements show 15 ft. of good ore.

A drift is located about 50 ft. east of the shaft just mentioned. It was started as an open-cut and driven 80 ft. through barren material, when ore was struck, dipping 30° E., and the drift was continued 20 ft. further, all in ore.

About 75 ft west, and a little north from the above drift, a shaft has been sunk, said to be about 60 ft. deep. The material on the dump shows that all the ore taken from this shaft was soft ore, of which possibly one-third is high-grade material, the average of the rest being low-grade. No hard bluish or lump ore is visible at this point.

In the same neighborhood a shaft about 30 ft deep passed through some ore of fair to good quality, but most of the material was of medium grade. A drift near by, about 30 ft. long, shows about 12 ft of ore, dipping 40° E., but does not expose any high-grade material.

On the opposite side of the gulch from this group of openings a drift has been driven into the hill and a number of small open-cuts have been made at different points in the gulch. Some of them show some outcrop material of low-grade containing bunches or lumps of ore of fair quality, but all of them are comparatively superficial and failed to reach workable ore.

At the locality of this Chicago group of openings there is doubtless a large vein or deposit of ore, but the strike of the deposit being nearly parallel to the hillside upon which the developments have been made, the apparent quantity of ore and size of the ore-body may be exaggerated by the fact that these developments are spread out along the trend of the deposit, and cannot be considered as indicating the thickness of

the ore-body This condition is intensified by the fact that the dip of the ore-deposit and the slope of the hill are in the same direction It is unfortunate that the development at this point was not intelligently directed, for the work done is more than sufficient to have explored the deposit and determined the thickness of the ore-body I believe the surface indications here furnish a safer index to the thickness, character and extent of this deposit than the openings which the owners have made upon it, and that the expenditure of an equal amount of work, if properly directed, would demonstrate the existence at this point of an ore-deposit approaching, in quality and quantity, that at the Sunrise mine

Another group of openings was made in a fork of the cañon in which this Chicago claim is located, about half a mile southwest from the Chicago openings, and doubtless located on the same vein or ore-bearing horizon I did not visit these openings, being informed that they were merely made to ascertain the existence of ore at that point, and that no work had been done upon them to determine the thickness of the deposit. The ore which they exposed was similar to that seen at the Chicago openings.

The Stein Openings.

No. 51. Going up Whalen cañon, north-eastwardly from the Chicago claim, a number of openings, made in the hillsides on the west of the cañon, were seen at intervals for about two miles beyond the Chicago claim. None of them showed any high-grade ore, except that some of the soft paint-material, exposed at what is known as the Stein opening, about one mile from the Chicago, may be classed as high-grade.

The ground shows some ore-material at intervals all the way around the hill from these openings to the Chicago claim; and it has been assumed by many prospectors that this showing marks the outcrop of the Chicago ore-vein, running continuously around the hills into Whalen cañon. I doubt very much, however, whether this be true. These deposits look like secondary or replacement-deposits, of the character of those already described in the Sunrise Park country, and I think their presence throughout this area strongly implies the existence in the immediate vicinity of an extension of the Chicago vein or some other similar vein to the north-east through these hills. I be-

heve, however, that this vein is hidden beneath the cap-rock, and, therefore, does not present any outcrops in this vicinity.

Regarding the ore-deposit at the Chicago claim, which was examined by Dr Ricketts in 1889, I quote from his report as follows

"It will be seen that both of the tunnels on the Chicago strike the ore upon the outcrop and do not pass through it, consequently neither wall of the ore-body is exposed, and no estimate of its actual width can be made. However, the work done indicates a minimum width of 50 ft with neither wall found."

Regarding the Sunrise deposit, I quote from Dr. Ricketts's report as follows

"The workings both of the first level and the surface show a local widening of the ore-body. The maximum thickness shown is fully 150 ft, but as far as the developments go they seem to show that both east and west of the shaft the ore returns to about the width shown in the second level, and perhaps becomes somewhat narrower towards the east. But the surface indications make it certain that there is an immense body of ore extending from corner No. 4 of the Sunrise to the shaft near the east side of the claim, a distance of about 900 ft. Both east and west of these two points there is every reason to believe that the ore-body continues unbroken.

"The hematite in the immediate vicinity of the copper-ore is impure, but the contents of this zone of impure ore, although large, is insignificant when compared to the entire body of hematite. Should a width of 70 ft be assured for the 900 ft the ore-body is known to exist, the portion of the chute above this level would yield about 750,000 tons of ore. Unforeseen changes in the apparent form of the ore-body may occur that would largely change the figures, but so far as the development goes, the guess is a conservative one, and the actual available tonnage is more liable to prove much greater than much less."

It should be explained that this estimate by Dr. Ricketts was based upon an assumption that the ore contained in the deposit extended to the depth of the main drift, 110 ft. below the surface; but in making his estimate Dr. Ricketts deducts from this depth of 110 ft. 25 ft of ore near the surface, which contains some copper, estimating only an average depth of 85 ft. of ore, from the point at which the copper disappears down to the lower level. It is practically certain that this ore-body will continue to a depth of several hundred feet, and should the thickness and length of this deposit remain unchanged as it is followed in depth, the figures given by Dr. Ricketts would justify us in expecting a yield of 750,000 tons for each 85 ft. in depth on the deposit. In this estimate Dr. Ricketts has made no attempt at estimating separately the proportions of high-grade, medium-grade and low-grade ore which the deposit will yield.

The Indicator Vein, Ballarat, Australia.

BY T A RICKARD, STATE GEOLOGIST, DENVER, COLORADO

(Canadian Meeting, August, 1900)

IN "The Genesis of Certain Auriferous Lodes"^{*} Dr Don makes a reference to a curious vein-formation known as the "Indicator," which characterizes a portion of the Ballarat mining district, in Victoria, Australia. During 1890 and again in 1898 I had an opportunity of making a few notes, which, although somewhat belated,[†] may be worth adding to the observations recorded in the *Transactions* of the Institute.

The country of the Ballarat gold-field consists of the Lower Silurian slates and sandstones, which also enclose the reefs of Bendigo; but it is noteworthy that the successive anticlinal folds, and accompanying saddles of quartz, which distinguish Bendigo are not characteristic of Ballarat, the geological structure of which presents greater complexity.

That part of the district known as Ballarat East became famous early in its history on account of the large nuggets which were found in the alluvium, and subsequently it became further known because of a peculiar persistent black seam, traversing the bed-rock underlying the alluvial deposits, which was found to be associated with rich bunches of gold-ore, not only in the gravel that capped it at the surface but also in the quartz-veins which crossed it underground. The name of "Indicator" was early given. In 1871 Mr. Morgan Llewellyn directed attention to it as influencing the distribution of the gold. In the government quarterly report for December, 1888,

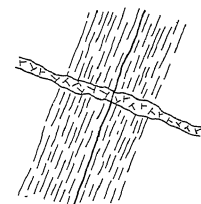
* *Trans*, xxvii, 564 *et seq*

† The treatise contributed by Dr. Don reached me while making a second visit to the very localities among which he has gathered so much valuable evidence. Most of the lodes to which he refers came under my own observation in 1889-91, and though I have omitted until now to join other members in acknowledging the great usefulness of Dr Don's contribution to the science of ore-deposits, it is solely due to the fact that I had hoped long ago to do so in a manner which he would most appreciate, that is, by contributing further data to the investigations in which he has been engaged

Mr. E. J. Dunn described* a similar occurrence observed by him in the neighboring district of Wedderburn. In September, 1893, the writer contributed a note on the subject.† Mr. Ernest Lidgley, of the Geological Survey of Victoria, made a special report‡ on the Ballarat East gold-field, which was published in 1894. In 1895 and again in 1897 Mr. William Bradford added further data §

Mr Bradford, who lives at Ballarat and has made a careful study of the district, describes the Indicator as "a pyritic sheet, varying in width from one-eighth of an inch to about an inch, which has been formed in an almost parallel line with the

Fig. 1



□ SANDSTONE ▨ SLATE

The Indicator (After William Bradford)

line of the strata. See sketch" The sketch referred to is reproduced in Fig. 1. Another good illustration from his later paper on the subject is reproduced, with slight modifications, in Fig. 2. The indicator is the dark thread G B, C H, which is dislocated from B to C by the fault-line A D. F B, C E is a flat seam of quartz which is also faulted, with enrichments at B and C, the points nearest to the Indicator and to the later line of fracture, A D. In his description of this occurrence he says

* "Report on the Country in the Neighborhood of Wedderburn and Rheola," by E J Dunn *Quarterly Rep of the Min Dept of Victoria*, 1888

† "Certain Dissimilar Occurrences of Gold-Bearing Quartz" *Proc Col Sci Soc*, vol 14, pp. 329-331

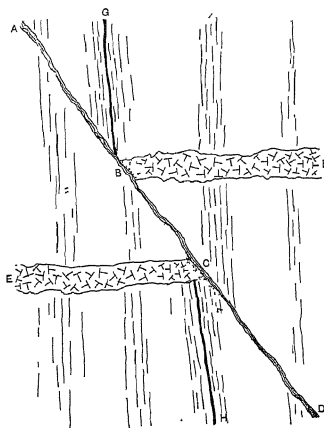
‡ "Report on the Ballarat East Gold-field," by Ernest Lidgley, assistant geological surveyor

§ "The Indicator Feature in Some Gold-Occurrences," by William Bradford *Trans Austral Inst of Min Engrs*, vol 14

"Flat make of quartz displaced by a slide break Nuggety gold was met with at the point where the Indicator intersected the quartz on the higher side of the break Down the line of the break a layer of gold in the form of fine particles was found, and traced to the point where the lower part of the quartz occurrence abutted on the break"

Mr. Dunn, the distinguished geologist, whose work on the neighboring gold-field of Bendigo is well known to the members of this Institute, describes the Indicator at Wedderburn as being a "bed of rock of dark-grey to black color, and from

Fig. 2



SCALE, 6 FEET

The Indicator Faulted (After William Bradford)

5 to 7 inches wide, made up of thinly laminated unctuous clay "

His illustrations are reproduced in Fig. 3.

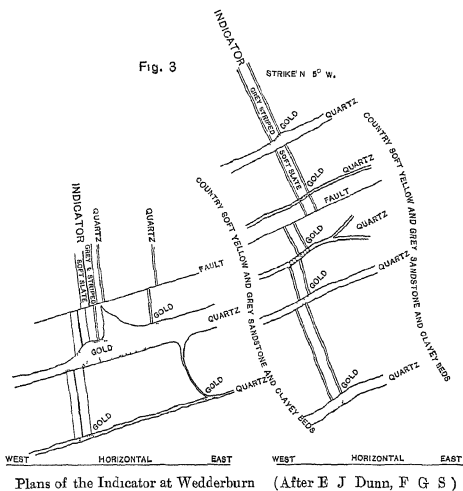
Mr. Lidgey, in his special report, says .

"These indicators are usually thin beds of dark-colored shales and slates, formed of a carbonaceous mud, containing a large percentage of non sulphide. They are parallel, and, so far as worked, nearly vertical, any change from the vertical being usually due to the presence of faults "

The most persistent of the series, known as "The Indicator,"

he describes as "a narrow bed of dark slate, usually showing cleavage planes, and containing a large percentage of pyrite, distributed irregularly through it." In Fig. 4 a series of Mr. Lidgley's illustrations is reproduced

Finally, in Fig. 5, I have added the drawing¹ exhibited by me in 1893 to the Colorado Scientific Society, from a sketch made at the 700-ft level of the New Normanby mine on February 25, 1891



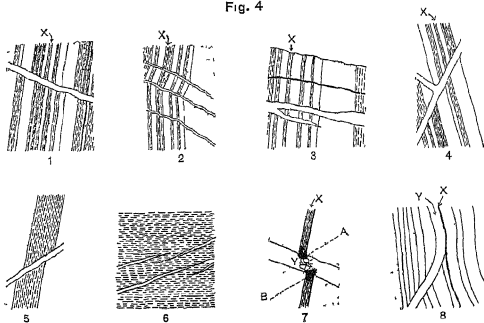
Whatever differences may be remarked in the foregoing descriptions are explained by the changes which this remarkable vein undergoes in its passage for seven or eight miles through a long series of mines, extending from Black Hill to Bunninyong

Mr. Lidgley's report is accompanied by maps of the Ballarat East district, exhibiting the course of the Indicator through a series of claims belonging to various companies. A part of

* This drawing was reproduced by Dr. Don, on p. 7 of his treatise, and in his paper, *Trans*, xxvii, 570

these maps is reproduced in Figs. 6, 7 and 8*, which represent the plan, cross-section and longitudinal section of the ground near the Prince Regent mine. Further evidence is given in Figs. 9 and 10. Fig. 9 is a photograph† taken at the 500-ft. level of the No 1 Llanberris mine. Fig. 10 is a diagrammatic interpretation which will, it is believed, aid the decipherment of the details in Fig. 9. The photograph shows the Indicator (at A B), and the foot-rule‡ affords a scale of measurement; yet, as in most underground photographs, the dark seams are confused by lines of shadow, and it is not possible to distinguish the slates from the sandstones, both being dark-grey and

Fig. 4



Diagrams Accompanying Report on Ballarat East (After E. Lidgey)

both showing cleavages. Nevertheless, it is a valuable piece of evidence, comparatively untainted with the subjective element which vitiates a sketch.

By way of supplementary testimony I add Figs. 11 and 12 from sketches made during my last visit to Ballarat, in January, 1898. In Fig. 11 the Indicator is shown as seen at the

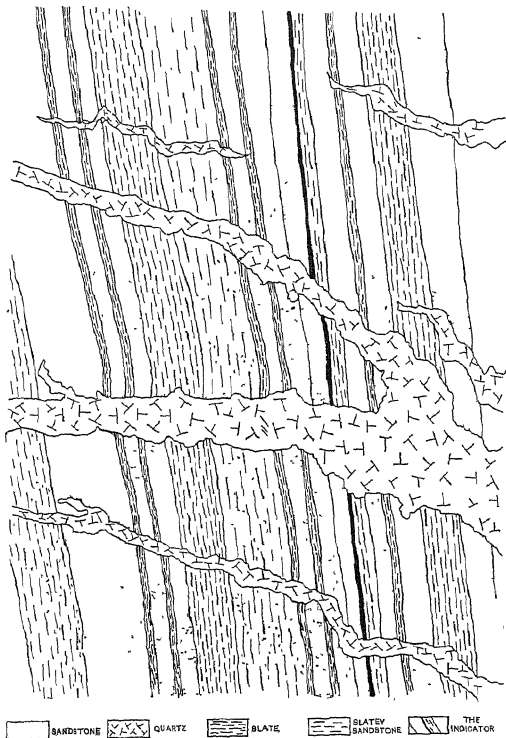
* These three drawings must not, I think, be taken too literally, for I note that the stratification of the slates and sandstones is repeatedly shown as unbroken where traversed by cross-courses which, as is well known, fault the country. Such errors are doubtless due to the departmental draughtsman who prepared the drawings, and do not represent any error of observation on the part of Mr. Lidgey himself. It was the dislocation of the Indicator series that the drawings were intended to represent; and thus they do satisfactorily

† This excellent photograph was kindly given to me by Mr. Lidgey in 1898

‡ Which, it should be noticed, is extended so as to cover a length of 2 feet

770-ft. level of the Prince Regent mine, where it is dislocated by a flat seam of quartz which carries coarse gold at the cross-

Fig. 5



"The Indicator," New Normanby Mine, Ballarat, Australia

ing. The Indicator evidently conforms to the bedding of the slate band, of which, indeed, it forms a part.

The Metropolitan lode, illustrated in Fig. 12, occurs in an

adjacent portion of the Ballarat district. It has, on a large scale,* certain of the features which characterize the geological structure of the Indicator series, and for this reason it is placed in evidence here. The Metropolitan lode consists of a series of spreading quartz-seams, to be considered as branches thrown out by nearly vertical veins, traversing a band (A B, C D) of thinly-bedded slates and sandstones, and dips slightly westward from the vertical. This band, which is enclosed by a series of massive beds of sandstone, forms a lode, or lode-channel, 80 ft. wide, in which the quartz-seams first referred to rarely exceed 7 or 8 ft. in thickness, and, having an easterly dip, cross the bedding almost at right angles. The cross-veins recognize the structure of the rocks they traverse by a succession of drops as they meet the successive seams of slate. The gold-occurrence is also modified by this structure, the richest quartz being found at the crossing of the slates, and especially upon the lower or eastern side. The quartz composing these seams is white "as a hound's tooth;" but occasionally, in the slate, it is besprinkled with a little arsenical pyrite.

The Indicator is essentially a very thin thread of black slate, which is remarkable on account of its extraordinary persistence, and also because the quartz-seams which cross it are notably enriched at the place of intersection. In certain parts of Ballarat East the Indicator has coincided with lines of movement, and having, on this account, undergone attrition, it now appears as a seam of clay. At other places it is so impregnated with iron pyrites as to have the characteristics of a sulphide streak. When it is met by quartz-veins carrying galena and zinc-blende it partakes of their mineralization. At the end of the 700-ft. level in the New Normanby mine it was slightly over one-sixteenth of an inch thick, and consisted of crushed black slate, in which small crystals of pyrites were embedded. In a cross-cut nearby it appeared as a thin vein of quartz. This is an infrequent modification, and one which is found by experience to be unfavorable to the occurrence of rich ore. At the 770-ft. level of the Prince Regent mine the Indicator had the thickness of an English penny, and was freely studded with crystals of arsenical pyrites, tarnished by oxidation.

The belt of slates and sandstones constituting the prevailing

* The scale of Fig. 12 represents feet, and not inches, as in Fig. 11.

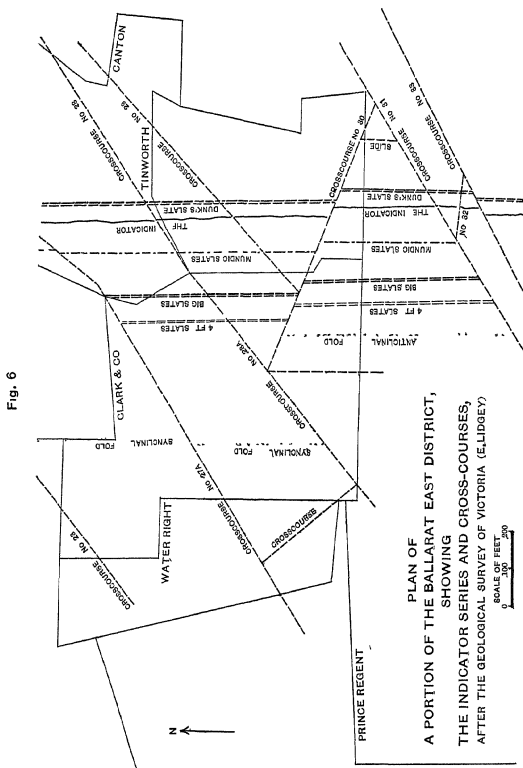
geological formation of the district is marked by a peculiarly persistent series of thin seams of black slate. The Indicator is the chief member of this series, by reason both of its persistence and of its economic importance as marking a line of particular enrichment. The others are variously known as the "Western Indicator," the "Pencil Mark," the "Nuggety Slate," "Dunk's Slate," "The Streaky Slate," etc.,—an odd nomenclature, originating with the miners, who have been quick to recognize these various "leaders," as they have been encountered in the workings underground. This series is crossed by a later system of quartz-veins and stringers, intersecting the bedding of the sedimentary rocks almost at right angles, and lying, therefore, approximately flat, with a slight dip northeast. Occasionally, large quartz-veins are seen following the planes of bedding, but such as do so, appear invariably to be poor. Those which cross the Indicator (and its companion-seams) are gold-bearing, but only at the places where they intersect the Indicator, and, as will have been noted in the illustrations, fault it. Therefore the workings follow the Indicator in such a way that the rock removed includes 2 or 3 ft.* on either side of it. The intersecting quartz-seams are so frequent that the entire band along the line of the Indicator is treated as a gold-bearing lode. Poor zones occur. Thus the Prince Regent mine has found no pay-ore on the Indicator between the 550-ft. level and the 770-ft. level. The Speedwell mine traversed a barren interval between 400 and 500 ft, but is said to have become profitable lower down. There is, however, at the present time, a general tendency toward impoverishment in the deeper workings of the group of mines occupying the Indicator belt.

The series of quartz-seams† which intersect the Indicator are not to be considered as isolated lenticles, but must be regarded as part of an extensive system of flat veins, which are lateral embranchments from the nearly vertical ones to be seen following the bedding of the slates and sandstones, as, for example, along B D, in Fig. 12. The workings of the mines exhibit frequent lines of faulting, or "slides," which dislocate the entire series referred to, *i.e.*, the Indicator, the quartz-seams en-

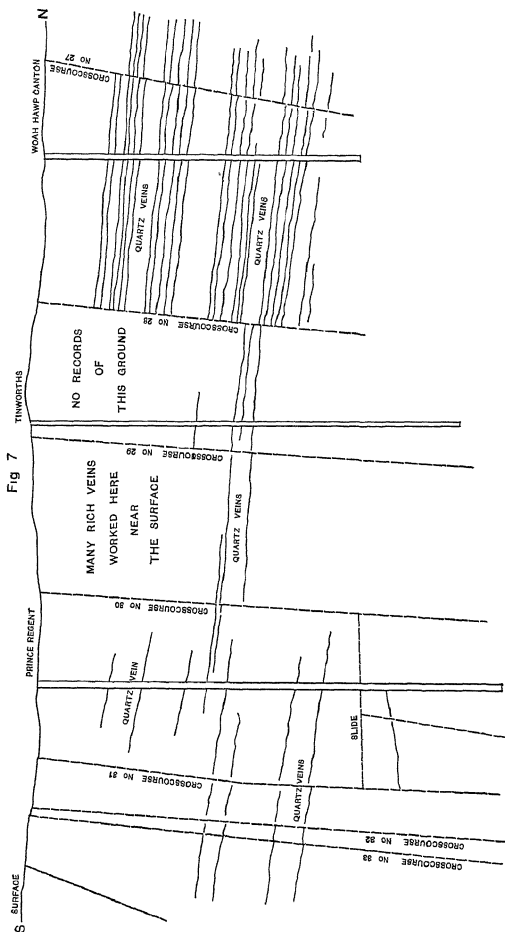
* As a rule a few inches on either side of the Indicator represents the entire width of the pay-ore, but 4 to 5 ft is necessarily removed for convenience of exploitation.

† The Australian miner calls these "makes of spurs."

riched by it, and the enclosing slates and sandstones. These "slides" carry clay and exhibit the other characteristics of planes along which a movement of the rocks has taken place.



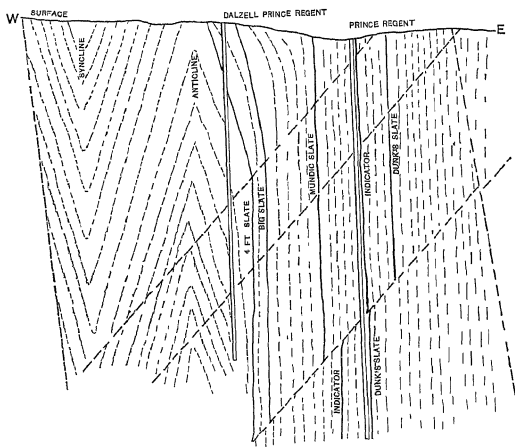
Mr. William Chisholm, the manager of the Prince Regent mine, who is thoroughly familiar with the geological structure of this part of Ballarat, regards the impoverishment below the



Longitudinal Section of Fig 6 (After E. Lidgley, Geological Survey of Victoria.)

550-ft. level as connected with the "big slide" which cuts through the shaft 540 ft. below the surface and shifts the Indicator series 55 ft. westward. The managers of the neighboring properties also connect similar disturbances encountered in the workings of their mines with the diminution in the richness of the series of flat quartz-veins. Dr. Don takes this view, and confirms it with analyses of samples taken in the Prince Regent mine, which prove that the solid country enclosing the veins is not itself gold-bearing, while the clay accompanying

Fig. 8



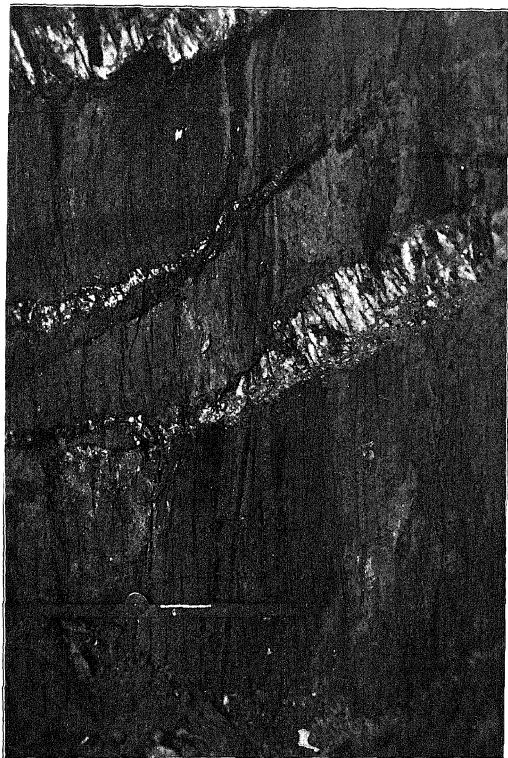
Cross-Section of Fig 6. (After E Lidgey, Geological Survey of Victoria.)

the fault-fracture is rich in gold. In both cases, the presence of gold bore no relation to the richness or poverty of the neighboring Indicator.

These views seem to me to be in accord with the evidence; but until the present horizon of impoverishment which characterizes the lower workings of the mines of Ballarat East is succeeded, deeper down, by a horizon of enrichment, one is scarcely warranted in speaking of "zones." My experience is, I believe, in accord with that of most of us, in recognizing the

fact that gold-veins often get poorer in depth; and this occurrence is so frequent that a particular explanation, like the one

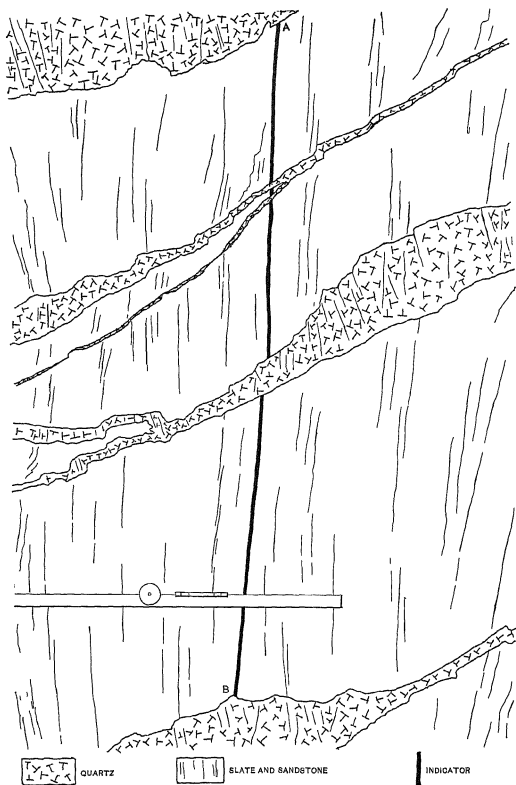
FIG. 9.



The Indicator, 500-ft. Level No. 1, Llanberris Mine.

above mentioned, gains no force by being connected with such a general fact. A zone of impoverishment is usually only a

Fig. 10



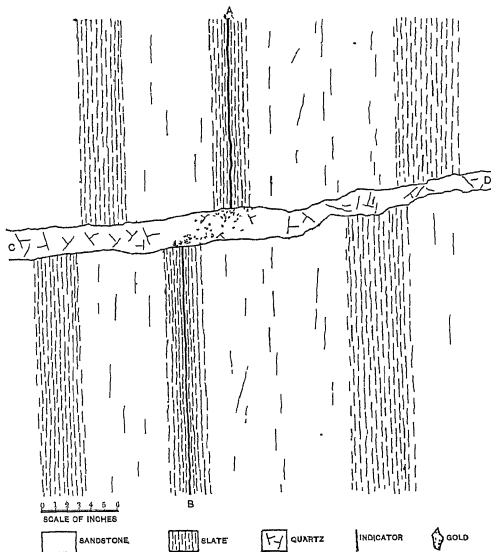
The Indicator Diagram, Explaining Fig 9

euphuism calculated to obscure the frank recognition* of things as they are.

* I was glad to read Dr Don's frank statement (*op cit*, p 596) concerning this matter of impoverishment below the water-level Science has to do with facts,

The enrichment of the selvage accompanying the fault-planes, as proved by Dr. Don, is very suggestive. If these faults served as passages for the upward circulation of the gold-bearing solutions which precipitated a part of their precious burden, *en route*, and the remainder when the Indicator seams were intersected, then we have a very pretty example of ore-

Fig. 11



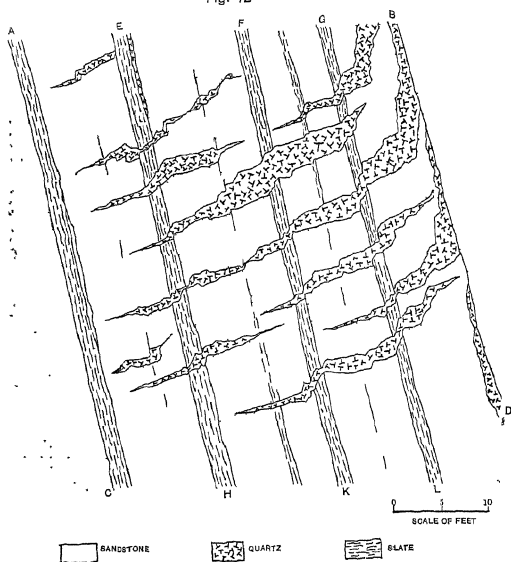
The Indicator, Prince Regent Mine, Ballarat

deposition. As yet, however, the evidence does not go much further than to accentuate the coincidence between the occurrence of rich gold-ore and a casing of carbonaceous rock. The organic matter observed in the Indicator seam, and also in the clay following the faults, is of particular interest, because it agrees with similar observations made in other mining regions.

nor can the industry of mining which is based upon the application of science be aided by fancies, however alluring

The graphitic slates of the neighboring district of Bendigo appear to have exerted a favorable influence on the deposition of gold. These, like those of Ballarat, are of Lower Silurian age, but the same coincidence marks the Devonian shales of Gympie, in Queensland, and the Jurassic slates of California. Small patches of peculiarly beautiful crystalline gold are found in the black Cretaceous shales of Farncomb hill, at Breckenridge,

Fig. 12



The Metropolitan Lode

Colorado; and at Rico, in the same State, a series of black shales and limestones of Lower Carboniferous age enclose the richest portion of a very extensive series of veins. In these cases the blackness represents the carbonaceous remnant of vegetable matter which was mingled with the silt and slime out of which the slates and shales were formed. In the case of so persistent and thin a seam as the Indicator we have to suppose

an extremely slow sedimentation, occurring in a large sheet of water undisturbed by cross-currents. The clay of the "slides," examined by Dr. Don, must have derived its carbonaceous constituent through mechanical action upon the edges of the slate-beds crossed by the line of faulting; the softer members of the series being, as I remember, the blackest.

This association of gold and carbonaceous matter has been investigated by Dr. Don with negative results, not only at Ballarat but also at Gympie. It would appear that where the black slates are gold-bearing they also carry a notable amount of pyrites. This was so at Rico, where I was able to make a careful study* of the veins which seemed to have been favorably affected by a graphitic encasement. But Dr. Don was looking in the enclosing rocks for the source of the gold, and not for a precipitant, because he is impressed with the fact that gold is so easily precipitated from its solutions that it is scarcely necessary to seek for a special agent. Nevertheless, accepting as I do the general theory of an ascending circulation as the basis of a science of ore-deposits, it seems to me that it is for the causes favoring precipitation that we must seek if we are to understand the vagaries of gold-occurrence. The experiments† made with the Rico shale illustrated the rapidity with which gold is precipitated from certain solutions when they come in contact with such carbonaceous matter. That there is also much black slate and graphitic shale which is not remarkable for containing rich gold-veins, is no particular argument against the value of the observation. The carbonaceous matter was probably only one out of several factors which favored the precipitation of the gold; and the pyrite, having been deposited previous to the gold, was probably another. But however that may be, it is an inquiry which must be left to painstaking investigators like Dr. Don, and not to mining engineers, who, like the writer, have not the time or the ability for such work. For us, and for the miners whom we direct, it is well to emphasize the fact that certain observed conditions, structural or physical, are favorable to the finding of gold, and if, in our daily work, we can collect further observations of this kind we shall have done something to aid the endeavors of the specialists who are patiently trying to unravel the mysteries which beset the genesis of ore-deposits.

* "The Enterprise Mine, Rico, Colorado," *Trans*, xxvi, 906

† *Op cit*, p 978

The Testing of Winding-Ropes in the Province of Anhalt, Germany.

BY FRANK H. PROBERT, A R S M, LONDON, ENG

(Canadian Meeting, August, 1900)

THE mining laws relating to winding-ropes in some of the German provinces are very strict, and severe tests have to be periodically made to see that the ropes in use come up to the prescribed standard. A few notes on the method of testing the ropes and the results obtained may be of interest to the members of the Institute.

Permission must be given by the Inspector of Mines to put up a winding-plant; and previous to installation a full report made by the manager, clearly setting forth all details of the shaft, the pit-head, engines and appliances appertaining thereto has to be sent to the mining officials. Accompanying each subsequent report, further details, such as the name of the firm supplying the rope, construction, quality of steel, date of installment, weight per meter, length, particulars of the safety-catches, cages, etc., must be given.

At least one spare rope must be kept at every shaft ready for use in case of emergency.

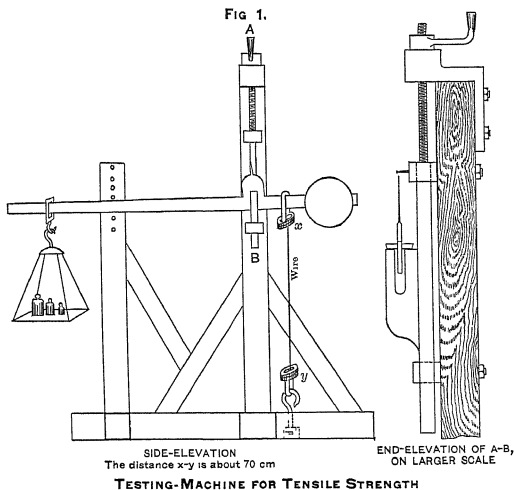
The rope must hang in the shaft, with cage attached, not less than twenty-four hours before it is used for winding; and it must have undergone a severe test in the manner hereafter described.

The laws prescribe that when a rope is continually in use it must be tested every three months; but if the rope is only used every few days it must be tested at least every six months, in the presence of the superior officer, and notification of the date of testing has to be sent to the *Bergrath* two days before the test is made, in order that he can personally superintend the operation if he chooses.

Should winding have been stopped for a long time, it is not necessary to test every six months; but before the rope can be used again it must be tested.

Every two weeks the shaft must be thoroughly examined by the underground foreman, to see that the runners are in good order, while at the same time another man allows the rope to pass slowly and loosely through the hand, to see that no wires are broken. A special book is kept, to be signed by those carrying out these fortnightly tests.

For the other tests, a length of not less than 3 meters is cut off from the cage-end of the rope. This 3 meters is reckoned from the top of the safety-clutch, so that, counting that part



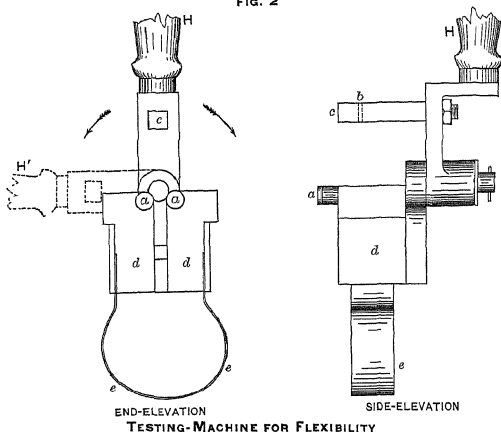
of the rope which forms the splice, from $3\frac{1}{2}$ to 4 meters are usually cut off. The one meter above the splice is that selected for the test

The meter chosen is untwisted and thoroughly cleaned, to remove the grease with which the winding-ropes are smeared. The central core and the small cores of each strand are laid on one side and not tested. Each individual strand has to be kept separate, and the wires making up the strands are all numbered.

The flexibility and the tensile strength of each wire is determined.

To find the breaking-weight, a rough testing-machine, shown in Fig. 1, is used. One strand is taken at a time, and each wire of it is proved before another strand is touched. The wires are taken in order, and tightly clamped between the jaws, which, being about 70 cm. apart, leave a length of 30 cm. to be tested for flexibility. Successive weights of 1 pound ($\frac{1}{2}$ kilo) are put into the scale-pan, time being allowed for the stretching of the wire. The elongation is taken up by the

FIG. 2



screw shown. Sufficient weights are added to break the wire, and the fracture is examined with a hand-lens, to see that no flaw exists.

That part of the wire which has not been submitted to the strain is now tested to determine its flexibility. A small hand-machine (Fig 2) is used for this purpose. The wire is threaded through a small hole in the projecting arm, and tightly clamped between the jaws by means of a vise. The small cylinder marked *a* must be 10 mm. in diameter. The wire being placed in position, the handle is moved alternately right and

left through an angle of 90° from the vertical. This must be done without jerking until the wire breaks—the number of turns being noted. From the vertical, through 90° and back to the vertical, counts as one turn. In this way every wire is tested.

Wires up to 2.0 mm. in diameter must be able to stand 8 turns before breaking; wires from 2.0 to 2.2 mm, 7 turns, from 2.2 to 2.5 mm, 6 turns; from 2.5 to 2.8 mm, 5 turns; and then of 2.8 and upwards, 4 turns.

The tests being finished, the results are tabulated as shown below. The weights in kilogrammes are added together and divided by the number of wires. This total is diminished by 20 per cent., and any wire that cannot bear the strain equal to the weight thus obtained is not included in the calculation. Also, any wire that cannot stand the number of turns prescribed for it is thrown out. When one rope is used for hoisting both men and mineral, two things have to be determined: (1) the relation between the tensile strength and the strain that is usually put upon the rope when hoisting men, and (2) the same relation when hoisting products. For these purposes, a fair average is taken of the weight of four men—the number usually carried in one cage—and also that of a wagonful of ore. To this is added the weight of the rope, cage and safety-appliances. The total is divided into the sum obtained above, and we thus establish a ratio between the actual strain the rope will bear and the strain the rope is always submitted to when winding. This ratio must not be less than 6 to 1. Should it fall below that, the rope is condemned.

No rope is allowed to be used for more than three years, no matter how good it may be after the lapse of this time, unless special permission is obtained from the Chief Inspector of Mines.

Having thus briefly described the method of testing, I will call attention to the results obtained from some ropes I have tested, which have brought to my notice one or two interesting points.

I give here a full report on one of the ropes used at the mine of Meiseberg, in order to show the form in which the results are sent to the Inspector of Mines. The calculations referring to other ropes I have briefly summarized in the following tables and plotted the results. All the ropes were of the "Lang's lay" pattern.

TABLE I — *Winding-Rope from the Meiseberg Mine—First Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date of installment, 19th April, 1895 Date of cutting the test-piece, 18th April, 1895. Details of rope: Length, 350 m.; weight, 521 kg, diam, 21 mm

Manufactured from the best crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm dia, core of 7 wires, each 1 mm diam to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1	1	305	21	Each wire must have a breaking-weight of at least 224 kg, and be able to stand 8 turns through 180° before breaking
	2	235	21	
	3	300	19	
	4	280	19	
	5	260	25	
	6	275	21	
	7	245	20	
	8	300	16	
2	1	295	19	All the wires come up to the standard demanded by the law, as regards both breaking-weight and elasticity.
	2	265	26	
	3	290	22	
	4	265	24	
	5	300	23	
	6	255	21	
	7	250	22	
	8	280	24	
3	1	255	25	<p><i>Winding of Products</i></p> <p>1710)13410(7 84</p> <p>11970</p> <p>14400</p> <p>13680</p> <p>7200</p> <p><i>Winding of Men</i></p> <p>1250)13410(10 78</p> <p>1250</p> <p>9100</p> <p>8750</p> <p>3500</p> <p>Neudorf, 20th April, 1895.</p> <p>Signed,</p> <p><i>Mining Engineer</i></p>
	2	255	23	
	3	315	18	
	4	285	20	
	5	280	24	
	6	315	16	
	7	255	24	
	8	290	22	
4	1	290	24	
	2	290	20	
	3	275	21	
	4	290	22	
	5	310	20	
	6	270	25	
	7	270	20	
	8	290	18	
5	1	290	20	
	2	255	24	
	3	280	22	
	4	290	22	
	5	270	20	
	6	240	23	
	7	275	23	
	8	280	21	
6	1	275	21	
	2	290	25	
	3	290	25	
	4	285	20	
	5	300	18	
	6	285	20	
	7	280	23	
	8	270	27	
Total		13,410		

TABLE II.—*Winding-Rope from the Meiseberg Mine—Second Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date of installment, 19th April, 1895 Date of cutting the test-piece, 12th August, 1895 Details of rope Length, 350 m. , weight, 521 kg ; diam , 21 mm

Manufactured from the best crucible-steel

Construction 6 strands of 8 wires, each 1 8 mm diam , core of 7 wires, each 1 mm diam. to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1	1	295	22	Each wire must have a breaking-weight of at least 226 kg , and be able to stand 8 turns through 180° before breaking
	2	310	32	
	3	305	26	
	4	280	19	
	5	275	20	
	6	260	23	
	7	285	16	
	8	270	20	
2	1	305	20	All the wires come up to the standard demanded by the law, both as regards breaking-weight and elasticity
	2	285	21	
	3	295	19	
	4	260	21	
	5	270	27	
	6	275	26	
	7	290	20	
	8	260	21	
3	1	300	24	<div style="text-align: right;"> <i>Winding of Products</i> 1710)13520(7 90 11970 15500 15390 1100 </div>
	2	265	24	
	3	280	22	
	4	290	19	
	5	275	26	
	6	270	21	
	7	300	15	
	8	290	24	
4	1	275	19	
	2	255	21	
	3	275	22	
	4	290	14	
	5	285	43	
	6	295	26	
	7	295	22	
	8	285	24	
5	1	300	20	
	2	290	20	
	3	315	19	
	4	235	14	
	5	285	20	
	6	275	20	
	7	290	25	
	8	270	22	
6	1	265	26	<div style="text-align: right;"> <i>Winding of Men</i> 1250)13520(10 81 1250 10200 10000 2000 </div>
	2	245	28	
	3	310	19	
	4	285	18	
	5	260	27	
	6	290	25	
	7	305	22	
	8	305	19	
Total		13,520		Neudoif, 16th August, 1895 Signed, <div style="text-align: right;"><i>Mining Engineer</i></div>

TABLE III.—*Winding-Rope from the Meiseberg Mine—Third Test*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date of installment, 19th April, 1895 Date of cutting the test-piece, 15th November, 1895 Details of rope Length, 350 m, weight, 521 kg, diam, 21 mm

Manufactured of best crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm diam, core of 7 wires, each 1 mm diam to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1.	1	260	25	Each wire must have a breaking-weight of at least 222 kg, and be able to stand 8 turns through 180° before breaking
	2	280	19	
	3	265	21	
	4	285	21	
	5	285	21	
	6	305	17	
	7	280	22	
	8	290	52	
2	1	290	25	The wire No. 7, strand 3, falls below the standard required by the law as regards breaking-weight, hence it must be deducted from the total
	2	300	33	
	3	290	30	
	4	255	22	
	5	300	21	
	6	290	22	
	7	265	23	
	8	295	18	
3	1	300	24	$13495 - 215 = 13280$ <i>Winding of Products</i> 1710)13280(7 76 11970 13100 11970 11300 10260 1040
	2	275	30	
	3	300	37	
	4	295	21	
	5	280	24	
	6	300	18	
	7	215	25	
	8	270	23	
4	1	310	20	<i>Winding of Men</i> 1250)13280(10 62 1250 7800 7500 3000
	2	290	20	
	3	285	24	
	4	295	18	
	5	270	20	
	6	275	20	
	7	320	16	
	8	295	23	
5	1	270	20	Neudorf.
	2	280	20	
	3	270	15	
	4	310	22	
	5	255	18	
	6	280	21	
	7	280	20	
	8	300	30	
6	1	275	24	Signed,
	2	260	20	
	3	270	22	
	4	270	27	
	5	290	28	
	6	275	19	
	7	255	18	
	8	245	19	
Total		13,495		<i>Mining Engineer</i>

TABLE IV — *Winding-Rope from the Mauseberg Mine—
Fourth Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date of installment, 19th April, 1895 Date of cutting the test-piece, 10 March, 1896 Details of rope Length, 350 m , weight, 521 kg , diam , 21 mm

Manufactured from the best crucible-steel

Construction 6 strands of 8 wires, each 1 8 mm diam , core of 7 wires, each 1mm diam to each strand

No of Strand	No of Wire.	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Rope	Remarks
1	{ 1	300	19	Each wire must have a breaking-weight of at least 240 kg , and be able to stand 8 turns through 180° before breaking
	{ 2	280	21	
	{ 3	295	21	
	{ 4	285	18	
	{ 5	300	27	
	{ 6	330	19	
	{ 7	310	19	
	{ 8	295	21	
2..	{ 1	280	17	All the wires come up to the standard demanded by the law, both as regards breaking-weight and elasticity
	{ 2	285	24	
	{ 3	295	26	
	{ 4	305	16	
	{ 5	295	20	
	{ 6	300	19	
	{ 7	280	24	
	{ 8	295	22	
3	{ 1	300	23	<i>Winding of Products</i> 1710)14385(8 41 13680 7050 6840 2100 1710
	{ 2	295	24	
	{ 3	295	24	
	{ 4	300	24	
	{ 5	300	33	
	{ 6	300	27	
	{ 7	325	21	
	{ 8	295	20	
4	{ 1	315	24	<i>Winding of Men</i> 1250)14385(11 50 1250 1885 1250 6350 6250 1000
	{ 2	290	23	
	{ 3	310	19	
	{ 4	300	17	
	{ 5	275	15	
	{ 6	290	22	
	{ 7	400	16	
	{ 8	285	24	
5	{ 1	305	16	
	{ 2	320	18	
	{ 3	335	32	
	{ 4	295	21	
	{ 5	280	21	
	{ 6	300	20	
	{ 7	345	19	
	{ 8	300	17	
6. ..	{ 1	315	18	Neudorf. Signed, <i>Mining Engineer</i>
	{ 2	300	19	
	{ 3	290	17	
	{ 4	305	21	
	{ 5	300	22	
	{ 6	290	18	
	{ 7	305	20	
	{ 8	295	18	
Total		14,385		

TABLE V — *Winding-Rope from the Menseberg Mine—Fifth Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date of installment, 19th April, 1895 Date of cutting the test-piece, 29 January, 1897 Details of rope Length, 350 m, weight, 521 kg; diam, 21 mm

Manufactured of best crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm diam, core of 7 wires, each 1 mm diam to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1 ..	1	295	35	Each wire must have a breaking-weight of at least 241 kg, and be able to stand 8 turns through 180° before breaking
	2	290	26	
	3	310	19	
	4	300	23	
	5	300	19	
	6	330	21	
	7	295	21	
	8	305	15	
2 ..	1	295	20	All the wires come up to the standard required by the mining laws
	2	290	22	
	3	300	19	
	4	300	16	
	5	300	23	
	6	315	28	
	7	285	18	
	8	310	22	
3 ...	1	295	18	<i>Winding of Products</i> 1710)14435(8.44 13680 7550 6840 7100 6840 260
	2	285	26	
	3	310	21	
	4	295	21	
	5	300	22	
	6	300	21	
	7	325	20	
	8	285	12	
4 ..	1	310	23	<i>Winding of Men</i> 1250)14435(11.54 1250 1935 1250 6850 6250 6000
	2	315	29	
	3	325	16	
	4	300	21	
	5	305	28	
	6	300	17	
	7	300	25	
	8	280	30	
5.	1	290	16	Neudorf, 3d February, 1897 Signed, Mining Engineer
	2	310	23	
	3	285	23	
	4	290	22	
	5	295	13	
	6	315	19	
	7	295	13	
	8	295	19	
6 ..	1	305	17	
	2	300	22	
	3	305	16	
	4	285	22	
	5	305	20	
	6	290	25	
	7	295	28	
	8	325	14	
Total.		14,435		

TABLE VI.—*Winding-Rope from the Meiseberg Mine—Sixth Test*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date of installment, 19th April, 1895 Date of cutting the test-piece, 14th July, 1897 Details of rope Length, 350 m., weight, 521 kg., diam., 21 mm

Manufactured of best crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm diam., core of 7 wires, each 1 mm. diam to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1	1	280	23	Each wire must have a breaking weight of at least 235 kg., and be able to stand 8 turns through 180° before breaking
	2	310	27	
	3	285	21	
	4	290	23	
	5	305	20	
	6	310	17	
	7	300	23	
	8	265	21	
2	1	300	17	All the wires come up to the standard required by the mining laws
	2	300	18	
	3	265	19	
	4	305	12	
	5	310	18	
	6	300	20	
	7	295	22	
	8	305	27	
3	1	290	21	<i>Winding of Products</i> 1710)14120(8 25 <u>13680</u> 4400 <u>3420</u> 9800 <u>8550</u>
	2	295	16	
	3	295	19	
	4	300	22	
	5	300	20	
	6	290	18	
	7	295	21	
	8	300	21	
4	1	285	14	<i>Winding of Men</i> 1250)14120(11.29 <u>1250</u> 1620 <u>1250</u> 3700 <u>2500</u> 12000 <u>11250</u>
	2	290	17	
	3	315	23	
	4	290	20	
	5	305	17	
	6	310	22	
	7	285	21	
	8	300	22	
5.	1	285	17	
	2	280	21	
	3	305	20	
	4	315	28	
	5	265	20	
	6	285	20	
	7	290	17	
	8	275	17	
6	1	290	24	Neudorf, 17th July, 1897 Signed, Mining Engineer
	2	290	16	
	3	280	18	
	4	300	18	
	5	285	25	
	6	290	16	
	7	315	15	
	8	300	25	
Total		14,120		

TABLE VII.—*Winding-Rope from the Meiseberg Mine—
Seventh Test*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895. Date of installment, 19th April, 1895 Date of cutting the test-piece, 3d March, 1898 Details of rope Length, 350 m , weight, 521 kg , diam., 21 mm.

Manufactured of best crucible-steel.

Construction 6 strands of 8 wires, each 1.8 mm diam , core of 7 wires, each 1 mm diam. to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1	1	290	12	Each wire must have a breaking-weight of at least 284 kg , and be able to stand 8 turns through 180° before breaking
	2	300	15	
	3	300	16	
	4	295	17	
	5	285	20	
	6	305	18	
	7	295	20	
	8	275	24	
2	1	300	27	Wire No 4, strand 6, falls below the standard required by the law as regards breaking-weight, hence it must be deducted from the total
	2	275	21	
	3	305	14	
	4	280	18	
	5	300	20	
	6	285	18	
	7	280	11	
	8	300	20	
3	1	280	18	$14050 - 225 = 13825$ <i>Winding of Products</i> 1710)13825(8.08 <u>13680</u> 14500 <u>13680</u> 820
	2	300	12	
	3	285	19	
	4	305	19	
	5	285	17	
	6	345	13	
	7	300	18	
	8	240	17	
4	1	295	17	<i>Winding of Men</i> 1250)13825(11 06 <u>1250</u> 1325 <u>1250</u> 7500 <u>7509</u>
	2	330	16	
	3	280	20	
	4	315	23	
	5	270	22	
	6	325	17	
	7	290	15	
	8	290	21	
5	1	315	20	Neudorf, 14th March, 1898 Signed, <i>Mining Engineer</i>
	2	290	18	
	3	295	20	
	4	300	19	
	5	280	21	
	6	290	20	
	7	295	17	
	8	290	21	
6	1	300	22	
	2	280	19	
	3	275	15	
	4	225	19	
	5	280	22	
	6	340	23	
	7	290	25	
	8	300	18	
Total		14,050		

TABLE VIII — *Winding-Rope from the Meiseberg Mine—
Eighth Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date when first installed, 19th April, 1895 Date of cutting the test-piece, 16th September, 1898 Details of rope 350 m long, weight, 521 kg, diam, 21 mm

Made of crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm diam; core of 7 wires, each 1 mm diam to each stand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1.	1	275	21	Each wire must have a breaking-weight of at least 225 kg, and be able to stand 8 turns through 180° before breaking
	2	275	21	
	3	280	11	
	4	275	19	
	5	300	17	
	6	270	25	
	7	275	23	
	8	295	20	
2. ...	1	275	19	All the wires come up to the standard required by the mining laws
	2	275	27	
	3	310	21	
	4	270	18	
	5	290	19	
	6	290	20	
	7	290	15	
	8	290	19	
3.	1	285	17	<i>Winding of Products</i> 1710)13490(7 88 11970 15200 13680 15200 13680 1520
	2	290	19	
	3	290	17	
	4	285	19	
	5	290	8	
	6	275	22	
	7	290	18	
	8	275	17	
4.	1	290	20	<i>Winding of Men</i> 1250)13490(10 79 1250 9900 8750 11500 11250
	2	265	22	
	3	295	21	
	4	275	21	
	5	280	20	
	6	245	17	
	7	265	20	
	8	280	14	
5. ...	1	275	19	Neudorf, 20th September, 1898 Signed, <i>Mining Engineer.</i>
	2	275	21	
	3	275	19	
	4	305	11	
	5	255	20	
	6	295	14	
	7	260	24	
	8	310	18	
6.	1	280	19	
	2	275	25	
	3	265	20	
	4	310	15	
	5	250	19	
	6	300	20	
	7	265	20	
	8	285	20	
Total		13,490		

TABLE IX.—*Winding-Rope from the Meiseberg Mine—Ninth Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date when first installed, 19th April, 1895 Date of cutting the test-piece, 17th March, 1899 Details of rope 350 m long, weight, 521 kg ; diam , 21 mm

Made of crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm diam , coils of 7 wires, each 1 mm diam to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1 .	1	300	16	Each wire must have a breaking-weight of at least 226 kg , and be able to stand 8 turns through 180° before breaking
	2	270	21	
	3	290	13	
	4	260	14	
	5	280	16	
	6	205	20	
	7	295	16	
	8	275	38	
2 .	1	305	15	Wire No 6, strand 1, falls below the standard required by the mining laws as regards breaking-weight, hence it must be deducted from the total
	2	300	17	
	3	280	26	
	4	280	19	
	5	290	15	
	6	300	19	
	7	310	22	
	8	290	20	
3 . . .	1	285	15	13560 — 205 = 13355
	2	265	14	
	3	290	14	
	4	285	19	
	5	300	16	
	6	275	20	
	7	265	20	
	8	290	22	
4	1	305	11	<i>Winding of Products</i> 1710)13355(7.81 <u>11970</u> 13850 <u>13680</u> 1700
	2	285	19	
	3	265	23	
	4	290	18	
	5	285	14	
	6	280	19	
	7	280	12	
	8	315	13	
5	1	295	16	<i>Winding of Men.</i> 1250)13355(10.68 <u>1250</u> 8550 <u>7500</u> 10500 <u>10000</u> 500
	2	280	12	
	3	285	20	
	4	230	16	
	5	305	21	
	6	300	20	
	7	255	17	
	8	270	21	
6.....	1	300	17	Neudorf, 23d March, 1899. Signed, <i>Mining Engineer</i>
	2	290	15	
	3	270	22	
	4	270	19	
	5	290	17	
	6	270	18	
	7	295	18	
	8	265	23	
Total		13,560		

TABLE X.—*Winding-Rope from the Meuseberg Mine—Tenth Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date when first installed, 19th April, 1895 Date of cutting the test-piece, 13th September, 1899 Details of rope 350 m long, weight, 521 kg., diam., 21 mm

Made of crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm diam., core of 7 wires, each 1 mm diam to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1.	1	275	20	Each wire must have a breaking-weight of at least 211 kg., and be able to stand 8 turns through 180° before breaking
	2	270	19	
	3	275	18	
	4	245	12	
	5	260	20	
	6	295	13	
	7	275	22	
	8	300	24	
2	1	245	12	Wire No 7, strand 5, falls below the standard required by the mining laws as regards breaking-weight, hence it must be deducted from the total
	2	270	28	
	3	260	18	
	4	275	22	
	5	250	13	
	6	285	21	
	7	270	15	
	8	270	18	
3	1	270	16	$12670 - 210 = 12460$
	2	245	11	
	3	265	19	
	4	280	23	
	5	265	29	
	6	240	19	
	7	265	27	
	8	270	25	
4	1	265	24	<i>Winding of Products</i> $1710)12460(7\ 28$ $\underline{11970}$ 4900 $\underline{3420}$ 14800 $\underline{13680}$
	2	240	19	
	3	280	29	
	4	245	16	
	5	295	22	
	6	220	21	
	7	260	19	
	8	285	21	
5	1	280	23	<i>Winding of Men</i> $1250)12460(9.96$ $\underline{11250}$ 12100 $\underline{11250}$ 8500 $\underline{7500}$
	2	275	24	
	3	270	22	
	4	270	21	
	5	275	22	
	6	265	19	
	7	210	22	
	8	250	36	
6....	1	255	17	Neudorf, 15th September, 1899. FRANK H. PROBERT, A R S M., <i>Mining Engineer</i>
	2	270	31	
	3	240	15	
	4	250	22	
	5	280	16	
	6	245	19	
	7	265	18	
	8	260	24	
Total.		12,670		

TABLE XI.—*Winding-Rope from the Meiseberg Mine—
Eleventh Test.*

Manufacturers of rope, Felten and Guillaume Date of delivery to mine, 17th April, 1895 Date when first installed, 19th April, 1895 Date of cutting the test-piece, 9th March, 1900 Details of rope 350 m long, weight, 521 kg, diam, 21 mm

Made of crucible-steel

Construction 6 strands of 8 wires, each 1.8 mm diam, core of 7 wires, each 1 mm diam. to each strand

No of Strand	No of Wire	Breaking-Weight in Kg	Elasticity No of Turns Through 180° to Break Wire	Remarks
1 . . .	1	280	20	Each wire must have a breaking-weight of at least 223 kg, and be able to stand 8 turns through 180° before breaking
	2	285	20	
	3	230	25	
	4	280	15	
	5	280	16	
	6	285	23	
	7	265	25	
	8	275	20	
2 . . .	1	295	21	All the wires come up to the standard required by the mining laws.
	2	290	19	
	3	295	23	
	4	285	20	
	5	265	21	
	6	295	21	
	7	275	22	
	8	280	14	
3.	1	260	20	<i>Winding of Products</i> 1710)13385(7 82 11970 14150 13630 4700 3420
	2	290	16	
	3	280	20	
	4	295	16	
	5	275	16	
	6	290	22	
	7	225	17	
	8	275	20	
4 . . .	1	280	21	<i>Winding of Men</i> 1250)13385(10 70 1250 8850 8750 1000
	2	280	18	
	3	295	21	
	4	290	20	
	5	285	19	
	6	275	17	
	7	290	24	
	8	270	22	
5.....	1	285	19	Neudorf, 13th March, 1900
	2	280	22	
	3	280	22	
	4	305	22	
	5	240	24	
	6	295	25	
	7	280	12	
	8	275	27	
6.....	1	295	17	FRANK H PROBERT, A.R.S.M., Mining Engineer
	2	295	20	
	3	260	22	
	4	275	21	
	5	280	15	
	6	265	25	
	7	295	16	
	8	265	15	
Total		13,385		

TABLE XII.—*Details for Diagram, Fig 3*

Curve No 1

Details of Rope	Date of Test	Months Elapsing Between Two Consecutive Tests	BREAKING-STRAIN	
			Winding Men	Products Every Day Strain Taken as 1
Manufacturers, Thomas and William Schmidt, Hamburg Length, 350 meters Diam, 21 mm Made from first quality English crucible cast-steel Construction 6 strands of 7 wires, each 1.8 mm. diam In each strand is a core of 6 wires, each 1.0 mm diam Central core of flax Date of delivery to Pfaffenberg Mine, 18th June, 1892 Date of installment, 7th February, 1896	April 22, '96 July 1, '96 Oct 26, '96 Jan 7, '97 Mar 13, '97 May 22, '97 July 29, '97	 2½ 4 2½ 2 2½ 2	12 50 12 74 12 80 12 63 12 31 12 55 11 85	9 65 9 86 9 90 9 76 9 53 9 71 9 17
Curve No 2				
Same as above	Same as above	Same as above	11 35 11 58 11 52 11 09 11 38 11 37 11 54	8 78 8 96 8 91 8 58 8 80 8 79 8 93
Curve No 3				
Manufacturers, Felten and Guillaume, Mulheim, Rhineland Length, 380 meters Diam, 21 mm Made of first quality English crucible cast-steel Construction 6 strands of 8 wires, each 1.8 mm. diam In each strand is a core of 7 wires, each 1.0 mm diam Central core of hemp Date of delivery to Pfaffenberg Mine, 17th August, 1897. Date of installment, 25th October, 1897	Oct 25, '97. June 3, '98 Dec 11, '98 June 8, '99 Dec 8, '99 June 12, '00	 7½ 6½ 6 6 6	11 28 10 53 10 56 9 92 10 23 10 64	8 79 8 20 8 23 7 73 7 97 8 29
Curve No 4.				
Same as above	Same as above	Same as above	11 03 10 43 10 68 10 20 10 35 10 51	8 60 8 12 8 32 7 95 8 06 8 19

TABLE XII—*Details for Diagram, Fig. 3. (Continued.)*

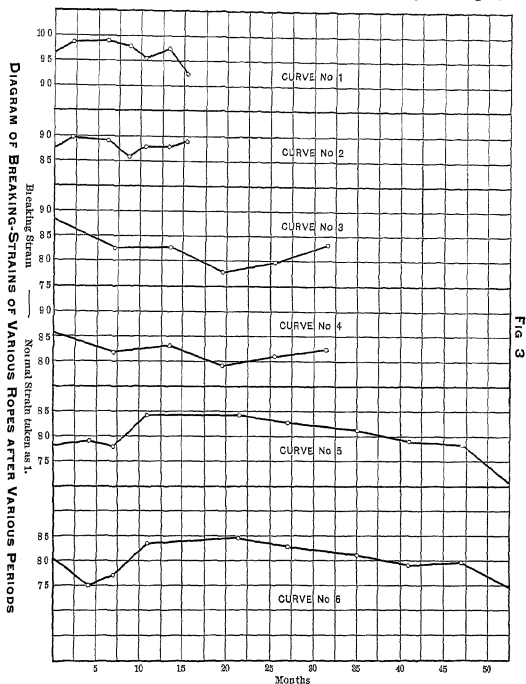
Curve No 5

Details of Rope	Date of Test	Months Elapsing Between Two Con- secutive Tests	BREAKING-STRAIN	
			Winding Men	Products Every Day Strain Taken as 1
Manufacturers, Felten and Guil- laume, Mulheim, Rhineland Length, 350 meters Diam., 21 mm Weight, 521 kilograms Made from the best quality English crucible cast-steel Construction . 6 strands of 8 wires, each wire 1.8 mm diam In each strand is a core of 7 wires, each 1.0 mm. diam Central core of hemp Date of delivery to Meiseberg Mine, 17th April, 1895 Date of installment, 19th April, 1895	April 18, '95		10 73	7 84
	Aug. 12, '95	4	10 81	7 90
	Nov 15, '95	3	10 62	7 76
	May 10, '96	4	11 50	8 41
	Jan 29, '97	10½	11 54	8 44
	July 14, '97	5½	11 29	8 25
	Mar 9, '98	8	11 06	8 08
	Sept 16, '98	6	10 79	7 88
	Mar 17, '99	6	10 68	7 80
	Sept 13, '99	6	9 96	7 28
	Mar 9, '00.	6	10 70	7 83
Curve No 6				
Same as above	Same as above	Same as above	11.02	8 05
			10 28	7 50
			10 50	7 67
			11 41	8 34
			11 58	8 47
			11 29	8 25
			11 08	8 09
			10.87	7 94
			10 93	7 99
			10 00	7 36
			10 85	7 93

The first and second ropes were not used long, because it was found that in every test there were invariably five or six wires falling, in both tensile strength and flexibility, below the standard required by the law, whereas the other wires were so good that the total was much above the prescribed sum, as is seen from the table.

All the ropes that have come under my notice at these mines have shown that after their installation their strength falls off, and subsequently rises. This characteristic does not always occur at the same time, but that it does happen sooner or later is shown by a cursory glance at the curves in Fig. 3. On seeing this, one naturally looks for an explanation, and I shall be

gratified if these few notes promote a good discussion. I am of the opinion that a molecular rearrangement takes place as soon as the rope is used. This movement may be very rapid or it may take months, according to the work put on the rope. Ropes Nos 1, 2, 5 and 6 were continually in use, day and night,



for the first twelve or fifteen months after their installment; but after that, ropes 5 and 6 were only used for winding ore every two or three days. Ropes 3 and 4 have never been much used, and, for the last eight or nine months, have been hanging idle in the shaft.

The Geology and Vein-Phenomena of Arizona.

BY DR THEO B COMSTOCK, LOS ANGELES, CALIFORNIA

(Canadian Meeting, August, 1900)

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INTRODUCTION.

SINCE 1892 the writer has published several articles in the *Engineering and Mining Journal* concerning the relations of the

principal vein-systems to the geognosy of Arizona and adjacent portions of Nevada and Mexico. Much has been written by local observers which might tend to leave the impression that no definite principles guide the engineer, either in exploration or in exploitation, in this region. But facts enough have now been gathered to prove that the diversity and complexity of the vein-structure are not so great as appears at first sight. There is a certain confusion of the geologic record in the more disturbed areas, which might be difficult to disentangle without the clues afforded by other districts, and this has often misled those who have not been able to make the needed comparisons.*

A discouraging misconception, largely due to the early mining history of Arizona, has seriously retarded the commercial progress of the Territory. The unfortunate portions of the history of Tombstone and the Silver King mine are ever-present "scare-crows" to many experts, notwithstanding two proved facts, which may not be as well known in our profession as they ought to be, viz. (1) that the Tombstone, Silver King, and some other *taboo* properties are not the mere surface-deposits they have been reputed to be; and (2) that the ore-bodies, or veins, of Arizona usually persist in depth and are as well defined by "walls" as the greater portion of the so-called "true fissure-veins" of Colorado. Much of the unmerited bad reputation of the Arizona districts named has been due to misunderstanding of their structure, and to stock-speculation, not based upon actual returns from the mines. Moreover, the developments made at great depths in certain veins of

* The conclusions here stated have been reached only after nine years of detailed study of the mines and veins of the region four years of traveling over the Territory as Director of the Arizona School of Mines, on various trips aggregating many thousand miles, chiefly in regularly-planned field work, well equipped for the purpose, and collecting largely from every mining county, and five other years spent in the same region in the practical management and development of mining properties, and in a varied practice as reporting and consulting engineer. The inter-relations of widely separated groups of veins have thus been brought most forcibly to my attention, and some further studies in adjacent portions of Mexico and California have demonstrated clearly to me what might not be so apparent without these opportunities. Prof John F Blandy, formerly Territorial Geologist, has at various times given me much detailed information, but is not in any way responsible for my conclusions.

the region fully justify the work done by Western engineers in direct contravention of the opinions of those who have not clearly understood the geologic history of the region. Perhaps no other region requires so much consideration of geognostic conditions in reaching a just conclusion as to the merits of individual properties *

A much respected member of this Institute, resident of an Eastern city remote from the mining regions, many years ago condemned the whole district around Prescott on account of the surface indications; and probably few engineers, without the knowledge of local geology possessed by some actual workers in this field, would have advised investment in any one of the largest producing mines, such as the Congress, Henrietta, McCabe, Little Jessie, King of Arizona, La Fortuna, Copper Queen, United Verde and others, from such evidence as they would have been able to gather in their early history. It is well known that nearly all who did examine these properties pronounced them worthless until their great value was proved by diligent exploration and exploitation. Undoubtedly the examiners were doing right to err upon the safe side; but the time has now come for the acquirement of more accurate knowledge.

A third fact of moment, which has but recently been appreciated, is the prevalence of gold in Arizona. There is a large class of gold-veins in the Territory, which was not even recognized until within the last few years. The writer announced this as early as 1892, giving abundant circumstantial evidence, and since that date numerous illustrations of importance have come to light.†

* The Silver King produced some of its best ore at the 700-ft level, and it is very probable that future exploration, based upon investigations such as are here outlined, will bring to light deposits of great value in directions not heretofore deemed encouraging. At any rate, the mine has not been opened extensively enough to disprove this contention, and the latest reports from this property are in accord with it. The history of the Tough Nut, at Tombstone, and of other mines in the vicinity, fully bears out my main assertion; and the same is true of many other abandoned mines in Arizona.

† See my articles in the *N. Y. Eng and Min Jour.* Those who care to follow up the statement will discover that all these developments have occurred in areas laid down by the writer of this paper, as early as 1893, as the auriferous ore-belts of the Territory.

Many valuable papers on Arizona ore-deposits have been published, mostly of local significance and based upon studies which only incidentally refer to areal geology. Witness. Arthur F. Wendt, *Trans.*, xv., 25, W. P. Blake, *Trans.*, xvii., 479, James Douglas, *Trans.*, xix., 688, *Trans.*, xxix., 511; S. F. Emmons, *Trans.*, Washington Meeting, February, 1900, pamphlet edition, pages 14-17*; and articles in the *Engineering and Mining Journal*, and elsewhere, by Trippel, Blake, Rickard, Penrose, Blandy and others. But the object of this paper is to help to clear the field for the minute study of local problems by securing proper recognition of the "geological relationships," the importance of which has recently been pointed out by Mr. Charles R. Keyes, in a paper read at the Washington Meeting of the Institute, February, 1900 †. No one appreciates more keenly than myself the influence of conditions not strictly geologic upon the formation and enrichment of ore-deposits; but the literature of the subject is deficient in fundamental studies. We know far more of individual results than of the life-history of vein-systems. However instrumental in vein-formation may have been the local environment and the operation of secondary agencies, a condition precedent to complete understanding of their effects is a knowledge of the regional geology.

The map on p. 1053 was compiled first from the best published hydrographic charts, then the county-seats, boundaries, railroads, and other details (including peaks, craters, etc.) were correctly located, without regard to any supposed relations; and the broken lines indicating axes of disturbance and vein-systems were drawn. The map did not grow out of any theory. On the contrary, the theory was strikingly suggested by the map.

It shows main features rather than details. Where vein-courses cross on the map, there is reason to seek the corresponding field-phenomena, though they be not apparent at first glance, by careful surface-examination, or sometimes, in individual mines, by study of the deeper workings, which may reveal what the surface does not. Of course, no mere surface-

* Present volume, pages 190-194.

† "Origin and Classification of Ore-Deposits," *Trans.*, xxx., 355

map could justly represent the actual structure. The purpose of this one is to give such general information as would be most practically useful; and while primarily illustrating this paper, it may serve as a preliminary guide for future workers

I. OUTLINE OF STRUCTURAL GEOLOGY AND MINERAL BELTS.

The sub-structure of Arizona may best be defined as a series of metamorphic strata extending downward to some early terranes, below the Silurian, not as yet fully determined.* Generalizations from our present knowledge must necessarily be somewhat loose, but the broad statement may be made that a traveler from the SW part of the Territory, in a general E or NE. course, to near the NE. boundary, might, without varying much from a direct line, pass up through the geologic series from the oldest to recent terranes. Speaking in most general terms, he would find some evidence of disturbance of a four-fold character until he had passed beyond the region of the Carboniferous exposures; but, before that, he would be impressed with the fact that the Carboniferous and pre-Carboniferous terranes had been mainly, or primarily, folded in a characteristic manner before the deposition of the later strata.†

Much work must be done before it will be wise to be very explicit concerning the actual epochal history of the region, but observations have not yet led the writer to infer that our tract is exceptional, except in degree. On the contrary, the orography can be very closely correlated with that of regions northward and southward, and the local peculiarities, aside from the result of secondary action, are usually traceable to inferior potential or greater resistance rather than to differences in kind or direction of the dynamic agents. The *loci* of the successive orographic throes are no less distinctive in their mineralization. The veins can all be conveniently grouped in four classes, as here outlined.

* This subject is treated more in detail in a later part of this paper.

† In the 2d Ann. Report, of the U. S. Geol. Survey, 1880-81, Major J. W. Powell, Director, it is stated (page xv.) that, in the Grand Cañon region, no dynamic break occurs between the Carboniferous and Cretaceous. This does not comport with my own observations (as I interpret them) in the region farther south.

1 *The Auriferous Belts of the Primary Uplift.*

Wherever the earlier, and now metamorphosed, strata (granitic-schistose series) constitute the surface formation, and wherever this has not been too much affected by subsequent upheavals, a series of folds trending nearly east-west may be discerned. This structure will here be described as the Primary Uplift, including the characteristically auriferous vein-series of Arizona. I do not feel sure that these veins are post-Carboniferous, but the uplift, which may have begun prior to the Silurian, was continued through the Carboniferous.

2 *The Silver-Lead Belts of the Mesozoic Disturbance*

In the post-Carboniferous strata the E-W folds are not apparent; but a series of NW-SE. faults of considerable magnitude has induced a remarkable topography, which has had most to do with Arizona's human, as well as geologic, history, and which, by reason of its dominant character, will coerce the mining development also within hard and fast lines. In the vein-courses of this type the greatest development of silver-lead ores has occurred.

3. *The Mixed-Ore Belts of the Cenozoic Uplift.*

A third and later epoch of disturbance was somewhat less momentous, geologically speaking, although accompanied by igneous outflows of much importance. But this earth-movement was the most significant, in one sense, to the miner, because of its effect in confusing and complicating the earlier structure and in commingling the vein-ingredients. The strata involved have been tilted at high angles in a NE.-SW. strike. The distinctive feature of the ores is the presence of gold in excess, in minerals usually deficient in this metal. The most important copper belts are also in this trend.

4. *The Rich Post-Tertiary (?) Silver Belts and the Crater-Cones.*

The fissure-trends traceable to this late epoch are radially disposed with reference to crater-cones, of which the San Francisco mountain-group, near Flagstaff, is a noticeable example. The veins of this series present more problems locally than any of the others, but they are not less important economically, al-

though they have always afforded more and greater stumbling-blocks to the reporting mining engineer. The mineral products are high-grade silver-ores as a rule. These four groups will receive more detailed consideration in the following section.

II. DETAILS OF GEOGNOSEY AND VEIN-STRUCTURE.

1. *The Primary Uplift*

The effects which may be traced to the uplift including the Carboniferous strata indicate that a coast-line then existed south of the present boundaries of Arizona, for the crumpling of the involved members into very numerous minor folds was a dominant characteristic. Yet this phenomenon is not by any means local in distribution. I have observed it over a very wide area, from the Humboldt river in western Nevada, as far south as the line between Chihuahua and Durango, in Mexico, and have reason to believe that the same feature is prevalent farther north and south. The effects betoken heavy pressure from the north or stubborn resistance from the south, or a combination of both. It is very difficult now to say how far the folding was carried in given instances, or how much the strata may have been shattered by this particular movement. The later dynamic manifestations have rarely left the structure in the best condition for estimating the relative quantitative results of each individual uplift. But judged from structural evidences, there seems to have been more vigorous action northward, and the differences observed in the mineral contents of the veins in Northern Arizona and Nevada and in Mexico thoroughly support this view.

The locus of each of the later disturbances, so far as these have affected the vein-formation, is not identical in geographic distribution. Therefore one may readily err in attempting to gauge the results of the earliest displacement in any field where one or other of the later movements has been pronounced. From a purely geologic standpoint, an error in such calculations would be less important than in local investigations by the mining engineer. But our mine-developments are mostly too superficial to give adequate answer to the question in detail. The age of this uplift may be pre-Silurian, although the general

trend of subsequent movements to the close of the Carboniferous period has been in much the same direction.*

(a) *Main Features of the E.-W. Auriferous Vein-Series.*—West of what is locally known as the "Rim"—the great bluff marking the line of the major fault of the Mesozoic series previously mentioned—the evidences of earlier folding along latitudinal axes are usually well marked, wherever the latest volcanic outflows have not obscured the underlying structure. It might be difficult to speak thus definitely from surface-observations of the region farther east, where denudation has been much less effective, but the developments of the Tombstone mines have shown that the primary foldings, with probably some complications due to later uplifts, are well represented below the surface. I have been able to trace this structure through the Huachuca Mts., eastward into the mines of Tombstone and Bisbee, and less frequent outcrops in northeastern Arizona exhibit similar features in smaller degree.† Further confirmatory evidences I have gathered from the region of the Swisshelm, Chiricahua and Galiuro ranges, and in the Superstition Mts., Pinal Mts., and other districts northward, all lying east of the "Rim."

This structure in the limestone is beautifully exhibited in the Huachuca Mts., and in the Mule Mts. in the neighborhood of Bisbee, where the folds are bold and less disturbed by later upheavals. In the Santa Rita and Santa Catalina ranges and the Sierritas, Coyote and Comobabi ranges and in the Whetstone Mts., the same ancient folding is readily traceable; and it is apparent, wherever the earlier terranes can be detected, in the cañons of the Gila river and its principal tributaries, and in the region northward, in and about the Black Cañon, and north-

* My more recent studies in Nevada have resulted in the discovery of intermediate orographic axes in parts of the complex, which otherwise corresponds to the Arizona system very closely. I believe that Professor Wm P Blake has done some work in this field which may add materially to our understanding of this question.

† Without making the same application of the facts, as far as I am aware, Prof W P Blake is entitled to the credit of first discovering this feature, in his work connected with the litigation of the early Tombstone companies. Mr W F Staunton, more recently the Manager of the Tombstone Mining and Milling Co., verified this discovery by his developments. Through his courtesy I enjoyed an opportunity to correlate this local structure with my observations elsewhere.

westward through the Cerbat range and beyond the Grand Cañon of the Colorado. With more or less modification, chiefly due to later history, the same record constantly meets the observer traversing the Territory northeastward. The gold-veins *par excellence* of western and southwestern Arizona are all exemplifications of this early type of fissures. The Homestake group and other veins in the Baboquivari Mts., in Pima co., well illustrate the class. Excellent examples in Yuma co. are the King of Arizona, La Fortuna, Mammoth (of Harqua Hala district), and numerous others, which are successfully worked. Other illustrations occur all over the valley of the Colorado river in Arizona, California, Nevada and Utah. The Mammoth mine and its neighbors, in Pinal co., and hundreds of others, including the Congress, in Yavapai co., the Gold Basin mines, in Mohave co., and prominent veins in Pima co., are cases in point. Certain features of some of these veins, due to subsequent history, may make them depart more or less from the normal type.

This striking structural feature is a fundamental element in the mining geology not only of Arizona, but also of considerable areas in Nevada and Mexico. It is the lack of this knowledge which has heretofore caused many errors in estimating the probabilities of development of the mines of this region. There is scarcely a prosperous gold-mine in Arizona which was not originally condemned by reputable engineers, on account of the very conditions which have since been found to be most encouraging for development.*

By carefully prolonging through this district the ascertained courses of the latitudinal gold-belts of the early series, the *loci* of the claims rich in gold will be determined. This principle, worked out in 1892 and later by the writer, was applied in 1895 in the selection of the Elkhart mines, and it may not be out of place to add that we are now mining ores carrying \$16 per ton and over, in gold, over the axis of an E.-W. sub-fold; while our neighbors, not thus placed, are getting, at the equivalent level, ore carrying but \$4 per ton. It must be added, however,

* Witness the United Verde, Congress, Crown King, Pearce, and a host of others, which are prosperous to-day. The McCabe, Little Jessie, Henrietta, Mammoth, Gladiator, and many more, may also be cited as equally striking instances.

that final comparisons of mines cannot be made on this ground alone. The veins of this (the Chloride) district are mostly of later origin than the auriferous epoch, and most of them have heretofore been worked for other than gold-ores. We have yet to consider in this paper their peculiar and independent characteristics.*

(b.) *Vein-Distribution and Vein-Structure of the E.-W. Auriferous Series.*—A marked feature of the vein-distribution of this series is its parallelism with the geognosy, that is to say, the veins not only follow in strike the trend of the folds, but also dip, at least in a general way, with the dip of the "country," repeating more or less closely variations in the latter. But I have not yet been able to detect evidences of such close relationship as would seriously militate against the intrusive character of the vein-fillings. In NW. Arizona, where the enclosing schists are nearly vertical, the gold-veins dip at high angles; whereas, in the southern counties, where folds in the strata are more moderate, the veins frequently dip at low angles.

But this statement cannot be practically applied, without reference to other considerations. There is, perhaps, no district in the region where the results of later disturbances are entirely lacking.† The free gold recently encountered in the Crowned King mine in Yavapai county, southwest of Prescott, beneath a superficial capping of sulphuret-ores extending from the surface to the 700-ft level, has generally been regarded as an anomaly. But to one versed in Arizona geology this discovery is really less unexpected than would have been the continuance of the superimposed conditions to indefinite depths. Other mines, such as the Gladiator, in the same district, are repeating the same evidence of the persistence of the latitudinal gold belts, at varying depths below the surface, in the regions affected by later orographic movements.‡

* Since the presentation of this paper, many striking examples of this structural feature have been observed in detailed studies by the writer in different parts of Nevada

† The gold veins of this series have never been observed (by myself) in any strata except the more ancient of the exposed series (beneath the Permian), and I am much inclined now to believe that none of them extend into strata later than the Lower Silurian.

‡ From 600 to 800 ft is about the depth roughly estimated by the writer in 1892 as the probable horizon of the sub-folds in that district. The calculation

This feature is specially noticeable in a tract adjacent to Chloride and Mineral Park, in Mohave co., where these indications are at times only superficial, but have a more evident meaning in the deeper workings of some of the mines. In a parallel vein struck on the 200-ft. level, of the Elkhart mine, we have ore yielding \$20 per ton in gold, and on the same level now prolonged northward to a point calculated to yield further evidences of the persistence of the auriferous belt, we are working a cross-vein of this type, carrying ore plentifully sprinkled with yellow pyrites, running well in gold. The gangue is entirely different from that of our main vein. We also have this new vein in our 300-ft. level. The Tennessee mine was worked for some years without revealing one of these buried cross-belts, which has finally been encountered in new workings. The gold-value of the mine-product has recently increased from \$4 to \$10 per ton. Other proof comes tardily from the Argyle claim of the Elkhart group. But these are only a few of the instances which might be cited.*

The gold-veins which appear to be most nearly in their original position in the trend of this early uplift differ much from those more recently filled. If not actually of igneous origin, they certainly exhibit features difficult to explain upon other hypotheses. The gold is usually free, in grains or nuggets, the latter sometimes of such great size and of such shape and surface-aspect as to resemble closely the metal congealed from a molten mass. These and the finer grains are not evenly distributed, and the associated minerals are liable to be found in bunches or patches unevenly distributed, perhaps precipitated in crevices in the mass from more recent aqueous solutions. The white quartz gangue is, for the most part, amorphous; and the veins are frequently interstratified, like intrusions in the slates and schists. Still further, there are striking instances of *brecciated fusion* and *cooling-lamination*, or

was merely a geologist's solution of an every-day problem presented by Nature, and it did not receive practical application until 1895, when I assumed charge of the development of certain properties selected by myself within this Tract, with such knowledge of conditions affecting the vein-formation as could be gained by close study of the local geology. The work which has been done there since has gone far towards demonstrating the truth of the propositions here announced.

* Similar zonal distribution of gold is apparent in recent developments on the Mineral Hill property in Yavapai county, now being worked by a Glasgow syndicate under the writer's management.

what very closely resemble such effects.* The Senator and President mines, in northern Mohave co., afford marked illustrations of these structural features, and the development of these deposits and of their extensions to the eastward, in Gold Basin, have given much color to the theory of igneous intrusion which is here tentatively announced. There are very similar features in the Mammoth district in Pinal co., and at the King of Arizona and La Fortuna mines, in Yuma co. I have observed the same structure in the Congress and neighboring mines, and in other localities in southern Yavapai co., and in a number of the mines in Pima co., and in veins of like environment in Nevada and Mexico. The Star Mines, near Cherry Creek, White Pine county, Nevada, exhibit both of these peculiarities in one prominent vein-system.

The Blue Dick mine, the Dosoris, some of the prominent veins in Crook cañon, and others on Groom creek and Lynx creek, all give further evidence of deep-seated conditions similar to those heretofore described, although the superficial structure is very different.

In the 400-ft. level of the Elkhart, we have encountered recently dikes of feldspar (white orthoclase) in close relations to this vein-series.

(c) *Vein-Contents*.—There is an important distinction between the effects of this primary uplift and those of later disturbances. We are unable yet to decide whether the vein-fillings were congenital with the uplift, or were secondary segregations from veins previously existing in the older metamorphics. There are evidences of igneous origin in the form of some of the quartz bodies and in the nuggets and grains of gold contained in the matrix; but the matter has not yet received the attention it deserves, and evidences of aqueous action are not wanting † It can only be asserted now, rather vaguely, that it is not certain how much influence the later dis-

* "Brecciated fusion" is here used to indicate a peculiar conglomerated texture which is evident more to the eye (by color) than to the hammer, the supposed fragments being thoroughly blended, as if by welding under the influence of great heat. By "cooling-lamination" is meant such a slabby structure as would be induced by the cooling of a molten mass under lateral pressure.

† For interesting facts bearing upon this question, see a paper by Prof. W. P. Blake, in *Trans.*, xxvi, p. 290 (Local references are made on pp. 294 and 295.) Prof. Blake has personally disclaimed any intention of putting such an interpreta-

turbances may have had in modifying such cases as point most strongly to the idea of aqueous origin. The fact remains that the east-west ante-Cretaceous terranes are traversed by veins which are distinctively auriferous and usually highly charged with the precious metal.

In Mexico, near the adjoining corners of the States of Durango, Chihuahua and Sinaloa, grains of native silver occur with the gold, and the presence of native gold, silver and copper in other districts in Arizona is usually accompanied with some hint of proximity to the same geologic feature. A marked example is the famous nugget field of Rich Hill and similar outcrops in the same belt, in the southern part of Yavapai co. The source of the rich placer-gold of the Greater-ville district, in Pima co., is probably the same.*

In the Elkhart workings we are approaching the 500-ft. level, but have not extracted ore to any extent below the 300-ft. level. The zone of surface-oxidation may be taken as extending to an average depth of 80 ft., which is, roughly speaking, about 70 ft. less than in the district around Prescott. In the latter area, the enrichment of the oxidized zone, or a portion of it, at the expense of the vein near permanent water-line, is a marked feature; but this is not as noticeable in the Mohave county mines, where the most pronounced feature of interest to the miner is the distribution of the gold in the sulphuret-ores.

Mr. Otto Kuencer, an engineer of many years' experience in Mohave co., who is very familiar with the mining developments, recently remarked to the writer that, "when the veins are worked to considerable depths, the iron sulphurets usually become dominant. If, then, one meets bodies of grey iron pyrites chiefly, there is little encouragement to proceed; but if the yellow pyrites become abundant, you have indications of a gold mine." Mr. Kuencer thus tersely expresses a fact which he does not attempt to explain, but which simply emphasizes the persistence of the cross-belts of the east-west gold-bearing series of folds and veins.

Certain properties along the length of the Cerbat range, Mohave co., in the course of the northwest trend, are highly auriferous; others are nearly barren of gold. Wherever the enrichment occurs, there are indications of the presence of

* Equivalent facts have come to my notice in Lander, Humboldt and White Pine counties, Nevada, since the preparation of this paper.

cross-veins of the earlier period, at greater or less depth below the surface; *per contra*, the impoverishment occurs always in places where the cross-veins are lacking. As nearly as can be safely affirmed from present knowledge, one vein-course passes between the Empire and Victoria claims, another runs across country about 2000 ft., or more, farther south, following nearly the course of the Argyle claim; the next one appears about 1200 ft farther south, in the Elkhart workings; one crosses the Tennessee ground, some 2000 ft. beyond, and others are manifest at similar, but varying, intervals southward, for many miles. A very strong belt passes through the Todd Basin, and many more are known and worked for gold all along the region farther south, in the Cerbat and Wallapai ranges. These crop out clearly in the course of the Colorado river farther west, and many others are traceable northward.

Vanadinite, wulfenite (lead molybdate), and, possibly, pyrolusite, occur in situations apparently indicating close relations to latitudinal gold-belts, but my observations lead me to regard them as the products of a later period; for their geographic distribution can be as well understood upon this supposition, and noted examples occur at the intersections of two lines of orographic movement. We shall have occasion further to discuss them in another part of this paper.

The most distinctive feature of this group of veins is the absence of sulphide-ores. Some engineers in their reports have assumed that molybdenum has here played the usual part of sulphur; but this view is wholly untenable, because the occurrence of compounds of that metal is exceptional, as explained in the preceding paragraph. It is not characteristic of this series. The free gold extends to an unknown depth and rarely yields evidence of the oxidation of pyrite, but rather suggests igneous origin, as before explained. The occurrence of silver under like conditions, when present, militates also in favor of this view. The presence of sulphides in the veins of the Congress belt is, I am confident, to be explained by subsequent infiltration; but the details are not yet worked out fully *

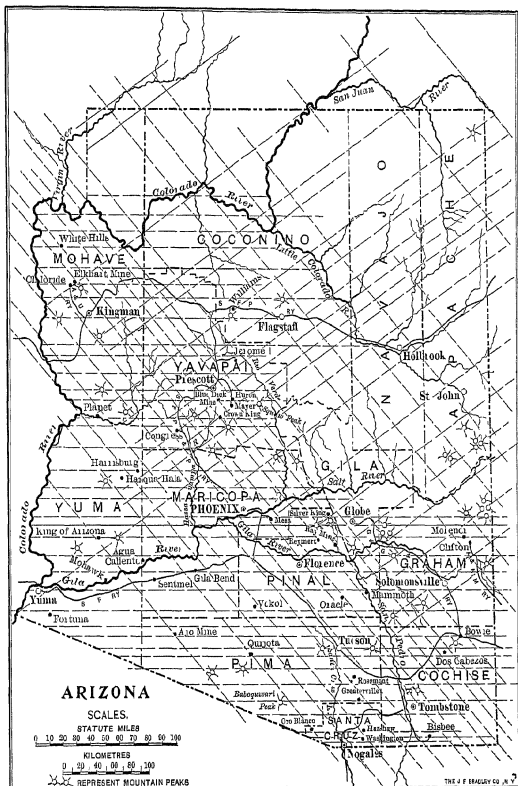
* The latest developments in the Congress mine afford remarkable confirmation of the views herein expressed, but they came too late for incorporation in the body of the paper.

(d.) *Boundaries of the Denuded Auriferous Field.*—On the accompanying map the area of the uncovered portion of the primal series of veins is fairly indicated. The effects of the later disturbances are by no means meager over the same tract; and one must not expect to find the early structure always apparent at a glance. Both faulting and igneous outflows have often caused complications of moment, and the excessive erosion of the greater part of the region has been inoperative in restricted districts. Besides these exceptions, a very large amount of detrital deposition has necessarily resulted from the extensive denudation of ages. But the boundaries placed upon the map will practically include the free-gold vein-exposures of the Territory of Arizona, excepting a very few outcrops within areas of typically distinct environment. Thus, there is a limited district within the Grand Cañon of the Colorado, and probably there are some others at points where local denudation has exposed pre-Permian strata within the borders of regions chiefly covered by later terranes. In practical studies, these anomalies need not cause trouble to one who keeps well in mind the general principles here enunciated.

The map shows also to some extent the marked tendency of the principal streams of this area to follow courses approximately latitudinal. This may be exhibited in a more startling manner upon a chart of sufficient dimensions to depict clearly the minor features of the topography. The Gila river, Salt river, Santa Cruz valley, Bill Williams Fork, branches of the San Pedro, the Babacomari and numerous smaller creeks, show well this coercion of the physiography of the district by its geognosy. And yet further, it may be demonstrated that the east-west streams of wide adjoining areas in Nevada, Utah, California and Mexico are similarly induced. The same features are also indicated by several prominent bends of the Colorado river along the line between Arizona and California, and by the determined guidance westward of the same river course in the districts outside of the distinctively auriferous tract.

There is a later structural line of the crater type which closely follows the auriferous trend. This is more evident northward, particularly in Nevada, but the two need not be confounded, if it be remembered that the later vein-course is rarely gold-bearing. An interesting occurrence of the two sets in one mine,

FIG 1



Map of Arizona, showing Structural Lines, Related to Ore-Deposits

NOTE—Since this map was engraved, the Santa Fe Pacific Railway (the E-W line through Flagstaff) has been formally incorporated into the Atchison, T and S F system. The N-S connecting line (through Prescott) still retains its separate name, as the Santa Fe, Prescott and Phoenix Railway. For further explanation of the map, see p 1041

only 30 ft. apart, had been observed by the writer in south-eastern Nevada.

2. *The Mesozoic Disturbance.*

(a) *Geognosy and Topography* —There may be some doubt whether the orographic effects now to be described have all been produced since the Cretaceous period. The question cannot be a serious one for the mining geologist, except, possibly, in restricted areas where this problem will become almost as local as the study of an individual mine. Over nearly all the country west of the great "Rim," in Arizona, there are few traces of terranes more recent than the Carboniferous, except the volcanic outflows and lacustrine deposits of later date than the Cretaceous. Evidences of vast erosion and extensive corrasion are very abundant, but I am aware of only a few exposures over this area which could even afford proof that the great faults had involved any strata later than the Carboniferous. Between Prescott and Ash Fork, on the Santa Fe, Prescott and Phoenix R. R., there is a striking example of the rising of the Carboniferous limestone above the level of the Jura-Trias across a minor fault; but, so far as my observations go, this was very near the western shore-line of the Jura-Trias. And the great "Rim fault," now rudely marked out by the Verde and San Pedro rivers, is at the same time a geographic diagonal of Arizona and its geologic hinge, or mid-rib; in short, its axis of evolution and revolution through all periods of its history, since these dislocations at the close of the Mesozoic Era, or earlier.

As already hinted, the orographic axes of this post-Carboniferous disturbance are well defined, long lines of faulting cutting across the latitudinal gold-belts at an angle of about 45 degrees in azimuth, with approximately vertical dip in the mid-fault of the series. The downthrow was apparently upon the eastern side of the great main fault, and the escarpment upon this edge still remains, practically, as a huge bluff, extending in almost an unbroken line, at least from Western Central Nevada, through Arizona, into and across Mexico, as far south as the northern portion of the State of Durango. I have reason to believe that this great fault extends far beyond, in Durango, but have never had the opportunity of tracing it beyond a point in the Sierra Madre, near Piedras Largas (Durango). East of this "Rim" (as it is

locally known along the Verde valley in Arizona, and might appropriately be designated throughout its length) denudation has been checked by the nearly horizontal position of the strata, but local "rims" have been produced along the eastern edges of several parallel faults, at varying distances eastward. Along these lines, as well as in the line of the major fault, erosion and corrasion have been active, owing to the crushing of the strata upon the upthrow (western) side, and, in some instances, to the exposure of the Carboniferous limestones at the surface. West of the mid-fault, denudation has been, for the most part, excessive; but there are other parallel fault-lines in this area, which have somewhat checked the erosion locally. There is also good ground, as hereinbefore stated, for the opinion that but little marine deposition took place subsequent to the Carboniferous period in most of the region west of the great fault except in the lower reaches of the Colorado river valley.

We do not now know enough of the structure underlying the country east of the "Rim" to be able to compare the outlying faults on that side with those upon the west. But the exposures along the western fault-lines seem to indicate greater tension from beneath or less resistance in the superincumbent strata, for the rocks are tilted nearly vertical and are often greatly hardened and compacted locally. This evidence is very well exhibited in the southern end of the Sierritas (a range of hills southwest of Tucson), and in the Coyote and Comobabi ranges, lying along fault-lines northwestward. Farther west the fault-lines (in Arizona) are not so readily traceable, by reason of the schistose and granitic character of the strata, but there are some excellent manifestations of the same structure in portions of Yuma co., notably in the Ajo, Eagle Tail and Plomas ranges (in one line); the Lomas Negras, S. H. and Dome Rock ranges (in one line), the Cabezas Prietas and Castle Dome ranges (in one line), and the Gila and Chocolate ranges (in one line), and in other small ranges, where many of the fault-fissures have been the channels of local igneous ejections.

Even the mighty graver, the Colorado river,—the course of which is now and again forced into successive fault-lines, but which has finally cut its way so deeply, in its lower reaches, as to go on apparently unguided by the faults more distant from the "rim-fault,"—has found these fractures most potent factors,

on the average, in shaping its course through Arizona and along its western borders.

On any reliable map of Arizona sufficiently large to exhibit clearly the main bends of the Colorado river, place a straight-edge along any line indicating a northwest or southeast course of the Colorado river, and you will thus trace the route of one or other of the faults, by prolonging the course southeastward across the Territory, and beyond, in Mexico. A similar extension northwestward will define the equivalent structure in portions of Utah and Nevada; but I am unable to give very much of this last from actual observation.* Probably some geological difference in that direction will abundantly explain the failure of the river to make its way persistently northward after the first turn into one of these fault-lines; indeed, the encountering of granitic rocks at the great southward bend may be amply sufficient to account for this new course. These features are illustrated upon the accompanying map

(b.) *Veins of the Lead-Silver Series.*—The significance of this epochal structure to the miner is the occurrence of veins of an entirely different order from those of the E.-W. auriferous series. There can be no doubt of their later formation. The veins of the NW. trend occupy the fault-fissures, and are unquestionably of aqueous origin. The silver-lead ores and the zinc ores of the Territory lie mainly in this series of fissures. There may be some modified deposits of this character with a different environment at the surface, but these will be found in a limited portion of the area affected by a third and later disturbance, to which attention will be given in this paper farther on.†

We do not yet know much about the source of these ores, which are invariably sulphides below the water-level. There is known to be a very considerable thickness of pre-Carboniferous strata beneath a portion of the country west of the "Rim." In a churn-drill boring made at Gila Bend, a few

* Since the reading of this paper, opportunity has occurred of studying the geology of much of that region also, and the results are such as to confirm and strengthen the view here announced.

† My most recent investigations in northern central Arizona (the Prescott region) emphasize the importance of this qualifying clause, but it possesses relatively greatest moment to the most superficial observer. Persons interested should give close attention to the discussion of the subject under the heading "3 The Cenozoic Disturbance"

years ago, for the Southern Pacific RR. Co., slight indications of oil and carbonaceous shales were met at a depth of several hundred feet. Suggestions of similar character are reported from the Colorado River valley, near Yuma; oil-sands have been brought to light in the southwest corner of Mohave co.; and the Grand Cañon section affords further illustrations. But there may also be some Tertiary relics to account for the bituminous material thus discovered.

The silver chloride ores, which are abundant at the surface in the path of the faults, may have been more or less due to the existence of salt beds which are not uncommon in favorably eroded tracts, particularly in Utah and California. The lead- and zinc-bearing minerals may, perhaps, have been derived from Silurian strata. The copper-ores of this system may have come, likewise, from sedimentary rocks of post-Carboniferous date, as the terranes most liable to be cupriferous have at one time formed, in part, the walls of the fissures. I should say, too, that the distribution and mode of occurrence of the copper-ores tend to confirm this hypothesis, which is further supported, mayhap, by the somewhat sparse mixture of the precious metals with these ores, save in exceptional cases. The reverse is the case, however, with silver in the galenas and blendes of the region.

It is more probable that the vein-fillings were due, not so much to the existence of the faults as to conditions subsequent, which have materially affected the area occupied by these belts of smelting-ores. Over a large portion of the area in question the detrital deposits are very thick. There are, however, some interesting exposures laid bare by more recent erosion, and we may hope to solve many of these problems, once we can gather such facts as await the observer.* Two features are prevalent

* I recently ran across an interesting item in a remarkable cañon near the SE end of the S. H. Mountains, in Yuma co. The ancient post-Carboniferous fault is largely obscured by detritus, but a fair vein of copper-ore defines its course, which is also paralleled by an igneous dike traversing granitic rocks. The main fault-fissure, farther NE, appears to have been the source of restricted lava-flows, now forming one side of the local valley, itself cut through lacustrine deposits, remnants of which form terraces along the cañon-walls. The hot springs of Agua Caliente lie only a few miles to the southeast, and the Southern Pacific RR. Co. gets a good supply of water from a well at Sentinel station, still farther along the same apparent fault-line.

in all the lead- and copper-mining districts which have yet attracted marked attention economically, namely, the volcanic rocks and the limestones. The former are not as prominent in Arizona as in the region northward; but it may be doubted if they have not had more influence in vein-formation. That is to say, it may be that the faults, and the dikes filling fissures in or near their paths, have together produced mineralizing effects more directly traceable than has been the case in districts where vulcanism has largely obscured the earlier history. But it must not be inferred that limestone is the only country-rock of the productive veins. While there is usually a much closer relation to the limestones than is commonly understood by our mining operators, there are, nevertheless, many excellent examples of veins in slates, porphyries and other country-rocks.

(c.) *Differentiation of the Mineral Belts.*—Although the copper-bearing and lead-bearing ore-belts are not sharply differentiated, viewed as a whole, yet there are such marked segregations of these minerals within the belts as to leave little doubt of their formation under diverse conditions. The United Verde mines, at Jerome, Yavapai co.; the Old Dominion and other mines, at Globe, Gila co.; the Copper Queen, at Bisbee, Cochise co., and the copper-deposits of Nacosari, in Sonora, all lie in one NW.-SE. belt, the main copper-belt of Arizona, occupying parallel fault-lines in a tract seventy miles wide immediately west of, and including, the "rim-fault." Similarly placed in fault-lines of the same belt are the noted silver-lead properties of the Chloride district, Mohave co.; the rich similar veins of the Bradshaw mountains, in Yavapai co.; the once famous deposit of the Pioneer district, and the Silver King mine, in Gila co., and the mines of the Tombstone district, Cochise co. As a rule, the silver-lead belt is broader than the individual copper-belts. The NW.-SE. line of this tract, prolonged northwestward, includes extensive similar deposits in southern Nevada and bears directly through the Comstock lode district. Although there is good reason for correlating this last-named region more directly with the Arizona silver-lead belt, I prefer to await the result of investigations soon to be made before announcing this fact too positively.* Following

* Since writing this, I have given the subject careful attention in the field, and am now prepared to assert that the conclusion here stated is strictly in accord with the facts.

the same course southeastward, the various well-known camps along the line of the Sierra Madre mountains, in Mexico, are evidently similar in origin, and my field-observations show that the structural features are, in effect, identical with those herein described for Arizona. The silver-lead ores of Chihuahua, Sierra Mojada, Batopilas, Parral, Santa Barbara, Guadalupe y Calvo, Piedras Largas, Guanacevie and other localities in the States of Chihuahua and Durango, are cases in point.

Within one and the same district similar variations occur, but the working of one mine for both lead and copper in the large way is as yet of rare occurrence, except in one particular region. I am disposed to attribute this remarkable specialization very largely to simple differences in temperature of the percolating solutions, causing deposition of lead and iron compounds at points where copper still remained in solution. This view is borne out, to some extent, by the distribution of the copper-ores, which are usually in situations indicating closer proximity to the seat of vulcanism. Exceptions to this rule are almost invariably deposits of secondary origin. The conclusion is also strengthened by the occurrence of the least soluble silver-minerals in places nearest to the seat of greatest heat at the time of volcanic disturbance.

Mr. Frank C. Earle, Assistant Manager, and formerly reporting mining engineer of the El Paso (Texas) smelting-works, whose knowledge of the mines of Arizona is wide and thorough, has informed me that some of the deepest worked lead-mines have yielded copper in the lower levels. A mere hint of the same conditions has been given by our own samples taken at Elkhart. These facts, I take it, are also in keeping with the views here announced.

There are other facts which do not comport as well with this hypothesis, but even these might be shown to belong to a different category, upon close examination. In southeastern Arizona, galena, blende and chalcopyrite are commingled in apparent exception to the foregoing rule; and the same conditions are evident farther southeast along the belt, in Sonora. Mr. Earle has kindly given me valuable information on this point, quoting the San Xavier mine, south of Tucson; the Pride mine, at Washington Camp, near the Mexican boundary-line, and the La Dura mine, on the Yaqui river, Sonora. Other instances

have come to my knowledge very recently from a part of the same belt in Santa Cruz co., Arizona, north of Nogales. This is a complicated district, and one in which both the copper- and lead-ores have marked expression individually, as at Bisbee and Tombstone, not widely separated. It would, therefore, not be surprising to meet with these double results in many localities. There is an enticing field here for detailed study. It is possible that the copper-ores are all of later origin, and it is certain that the later NE.-SW. trend is distinctively cupriferous in some portions of Nevada.

The foregoing outline, without further comment, will be found much safer as a guide to the engineer in the field than might seem probable to a cursory observer. But there are some important areal characteristics which appear to be, for the most part, resultants of diversity in dynamic effects, and particularly of differences in thermal intensity, along the several fault-lines. We may best discuss these variations after considering the constituents of the veins of this epoch as a whole *

(d) *Vein-Contents*—Pyrite, a very common constituent of the lead-bearing veins, is apparently less characteristic of the cupriferous deposits of this series. Where gold is abundant enough to appear in the lead, zinc and copper-ores, it is almost invariably much more prominent in the pyrites, but the distribution is peculiar and not similar to its occurrence in the ores of other districts. Referring again to the remark of Mr. Otto Kuencer,† it may be predicated that the massive pyrite is not usually the highly auriferous variety in the region of the veins now under review. Exceptions to this rule will be found in coarse crystals of cupriferous pyrite included in masses of galena or in intimate association with copper-ores. The gold is often largely contained in minute specks of yellow pyrites disseminated in quartz, and very rarely in white iron pyrites of any form.‡ Granular masses of pyrite crystals are almost invariably barren of gold

* Mere geographic relations are unsafe criteria, especially where the N W and N E vein-trends are concerned. After additional mining experience, gained since writing this paper, I am more inclined to believe that the copper-deposits lying in the N W trend are exotic, of coincident origin with the next later vein-series

† Quoted on page 1050, above.

‡ In the Elkhart concentrating plant we get practically all the galena out of the ore in the crushing before sizing, and the coarse pyrite is largely eliminated in the jigging, but the jig-tailings run high in gold. These tailings contain pyrite chiefly in minute particles, and no free gold.

Silver, though not plentiful in the pyrite, occurs sparingly in all of it. As might be expected, this metal is well distributed through the galenas, but it also exists in the form of sulphides and occasionally as native silver. There is at least a doubt whether these richer deposits are not all the results of later action; certainly many of them do not belong to the products of the epoch we are now considering.

Chalcopyrite is also in evidence. It has been stated by some experienced operators that this mineral is not indicative of the most permanent and profitable deposits of copper, being liable to run into pyrite in depth.* I believe it may yet be possible to put this vague statement into more explicit terms, but it is best not to rely implicitly upon it now, for some very extensive deposits of chalcopyrite are profitably worked in localities similarly situated. Probably it is safe to assume that the chances of continuance of the copper are, roughly, in inverse ratio to the excess of iron above the normal percentage in chalcopyrite. My latest observations incline me to the opinion that this criterion is not a safe guide in practice.

The glance-ores of copper appear to be more reliable precursors of valuable deep-lying deposits. The oxides and carbonates in the zone of oxidation vary widely in mineral character and in association. The "iron hat," which some demand as evidence of subjacent values, has become to the writer almost an indication to the contrary in judging copper-veins in this district.† But it is important to mention a striking instance of

* Mr C E Mills, formerly in charge of the Boggs smelter, at Arizona City, first gave me this information in December, 1896. My own observations confirm it to some extent, but my experimental studies, taken in connection with those of Dr A Von Streeruwitz, of Houston, Texas, have led me to infer that the application of the principle must be locally limited. The subject is not uninteresting, but too wide of our theme for adequate treatment at this time. Suffice it now to remark that I gave much attention, while acting as the Director of the Arizona School of Mines, to some experiments on vein-formation which were but fairly beginning to bear fruit when they were necessarily abandoned. One fact gleaned was the stubbornness of copper and lead, and the tractability of iron, gold (and silver, in less degree) to reorganizing influences.

† This opinion was, in a measure, due to the outcome of the experiments referred to in the preceding foot-note, but my later field observations and some experiments in developing copper properties in Arizona have more strongly emphasized the impression. The explanation must be left for a more suitable occasion. I do not mean that no "gossan" zone exists in which oxidation has occurred, but that *ferrie oxide* is not usually its substance.

the occurrence of hematite-ores in juxtaposition with rich copper carbonates. The illustration cannot be regarded as a contradiction of the previous postulate, because it is abnormal, or, more properly speaking, not a real case in point. At the Planet group of mines, on Bill Williams Fork, in the northeastern corner of Yuma co., large deposits of malachite form a contact-deposit between beds of hematite and limestone. These and neighboring outcrops are unique in their occurrence, which suggests a probable connection with some phenomenon of structure as yet unknown. It may be only the existence of iron-ore beds locally in the limestones of the region, or it may be some unexplained genetic feature of the veins themselves. The former view seems most tenable from present knowledge. The manganese deposits elsewhere noted are similarly placed, as far as my information goes. Perhaps it may also be necessary to refer to some very important instances of copper-deposits capped by iron cement, as at Rosemont, in Pima co.; the Dragoon mountains, in Cochise co., and elsewhere. But these are not true illustrations of "iron hat," which is due to simple oxidation.

Native copper and native silver occur in veins of this epoch but sparingly, and there is usually evidence at hand of the intervention of agencies effective in a later period, or of secondary alteration or segregation probably not coincident with the original vein-formation. The occurrence of native copper in considerable quantity at the Ray mine, in Pinal co., is presumably an example of local transformation of this character, and I am inclined to believe that the peculiar exhibition of native silver in lower levels of the Old Dominion mine, at Globe, Gila co., is another illustration of more recent results, to be hereinafter described. Probably, also, the remarkable segregations of native gold in a very similar way, in mines on Lynx creek, Yavapai co., must be explained in like manner.*

The rarer minerals, such as vanadinite, wulfenite, descloizite, dechenite, linarite, ecdemite, appear to be due to conditions for which the dynamism of this period is partly responsible.† All

* See discussion of this subject, p. 1088

† Mr. T. A. Rickard, in his admirable paper on "Vein Walls," *Trans.*, xxvi. (1896), at p. 234, in discussing similar occurrences in the Mammoth mine, remarks that "there seems to be no connection between the presence of these later min-

the reported occurrences of these minerals are at places where the crossing of prominent axes of the E-W. and NW.-SE. disturbances is evident. It may be added that certain differences in the several examples are readily explainable upon no other supposition. Thus, the vanadinite from the mines in Yuma co., at the southern end of the Castle Dome mountains, occurs in veins unmistakably allied to the most ancient E.-W. auriferous series, which bears important relations to the granitic rocks of the region. Likewise, the same mineral appears at intervals along a nearly due east course as far as the Mammoth mine, Pinal co., and there, too, the granitic rocks are evident. But there are many outcrops, identical in these respects, which do not yield similar minerals. Moreover, the same minerals, as shown, occur with suitable modifications elsewhere, under conditions which are not strongly pronounced in these instances here quoted. If careful scrutiny be given it will be ascertained that the structural features of both periods of disturbance are traceable at the points where these minerals abound. The differences are always due to the relative proportions of the vein-ingredients of the two series. I will not attempt now to decide what later influences may have affected the segregation of these interesting minerals, but it is very probable that local igneous action has played an important part, and that stratigraphic features or elements of vein-structure have been more or less instrumental in the process.

Tellurium-ores are possibly more abundant than we know. Such as have been discovered appear now to be properly included with the minerals named in the preceding paragraph, as far as their relations to geologic history are concerned. The Antelope mine, near Willow Spring, Pinal co., is a good illustration, and it lies almost directly west of the Mammoth, perhaps upon the same axis of the E-W vein-series. In the district north and west of Harrisburgh, in Yuma co., in situations very similar to those here indicated, there have been other discoveries of telluride-ores which are not exceptional in their occurrence.

erals and the formation of the ore-bearing parts of the lode." He is certainly right in adding. "They are the result of secondary processes," but the restricted distribution of such secondary results, and the geologic conditions invariably accompanying them, prove clearly that the generalization first quoted is too sweeping

Arsenic and antimony may possibly fall under this head; but my observations thus far lead me to infer that they are almost wholly the products of a later epoch.

Bismuth compounds have been recognized, in places, but the distribution is not yet clearly worked out.*

Large deposits of manganese-ore (black oxide) occur in connection with the rare minerals in four localities, viz. at Tombstone, Cochise co; the Silver Belt and neighboring mines, Yavapai co., the Silver Bell mine, near Reymert, Pinal co., and the White Hills mines, Mohave co. Probably other occurrences have been overlooked, or will come to light by further development. It is, however, extremely significant that these all lie directly in the line of the fault-series of veins we are now describing, and each one of the illustrations is from a district of very rich silver-ores. Moreover, evidences of proximity to strong expressions of the E.-W auriferous vein system are manifest at all these localities

3. *The Cenozoic Disturbance.*

Much detailed study must be given to the minor problems involved before it will be safe to attempt to formulate the typical structure of this period.

There is at least reasonable doubt whether two epochs of disturbance are not really represented by the complications of structure which, in point of time, succeeded those we have heretofore described. As yet we have gathered too little evidence to define the geologic history beyond bald outlines, but disconnected scraps of information gathered from exposures and from mine-workings lead me to group the earth-movements tentatively into two presumably distinct epochs, although the later one may have been coincident with the Crater-period next succeeding. It is only necessary to add here that the effects of the later throe are chiefly horizontal displacements of strata uplifted in the earlier epoch.

In the period succeeding the post-Carboniferous faulting, the region west of the "Rim" was less affected by earth-movements than a certain district indicated upon the map, in which the NE.-SW. trend of uplift is now most clearly evident.

* An impure grayish-green oxide has been reported from near Tucson, and the carbonate from the country north of Phoenix. *Mineral Industry*, vol. 11, p. 71.

From the fact that the conditions elsewhere were much more favorable for this manifestation, intensity of action being equal, it is evident that the cause for such restricted application was lack of potential, and not undue resistance, over the area in question. A little study of outlying regions will demonstrate the truth of this conclusion.

Utah, Nevada (in part) and a considerable area in Colorado and New Mexico evince much stronger effects of the vulcanism of this epoch. We have, in Arizona, some illustrations at remote points, but the orographic results are mainly local, except in the NE quarter of the Territory. As a general proposition, the resultant at any given point will be found inversely proportionate to the distance from the seat of greatest volcanic activity in central Colorado, full allowance being made for the resistance of the superincumbent strata

When the refined methods of investigation by detailed local surveys come to be applied, it will be feasible to determine much more accurately than is now possible the economic capacity of individual veins. All we can now do is to generalize broadly with a view to blazing out trails for better equipped workers to use as rough guides while building roadways into this little explored region.

The resultant physiognomy of the epoch is of prime importance in judging of the worth of properties within the area seriously affected by the Cenozoic disturbance. Ignorance of this significance has been the main cause of engineering blunders in examination and development of mining properties in the Prescott district, which presents the most striking phenomena of the whole tract.

As dynamic effects of this period, there are three (or more) induced geognostic and physiographic features, each with a meaning which no engineer can afford to overlook or misunderstand. The modifications of structure produced at this time may be grouped for consideration under the heads of dislocations, intrusions, and ejections. No epochal value can be properly attributed to any of these phenomena, as far as we know. It is probable that each result was due to local variations in resistance to the pent-up energy of a long-restrained molten magma. There is, however, a certain order of sequence which may afford a rough basis for classification. That is to say, the

dislocations, which are of two kinds, were apparently antecedent to the intrusions. The relations of the intrusions to the ejections, in point of time, are not clearly worked out. They now appear to me to have been non-synchronous, and in the order here given. But it is very difficult to distinguish between the igneous effects of this and the next succeeding period. Moreover, it is impossible, without more careful study, to determine the time of ejection of many local outflows of lava which have utilized much earlier fissures as escape-valves.

(a.) *Dislocations*.—Both vertical and horizontal movements are exhibited in the present position of the strata over a large portion of the district best illustrating the history of this period. The tilting of the formations cannot always be readily detected in the western part of the Territory, where it is probable that such effects were less intense, and more limited in extent. In a general way, the same assertion holds good of the horizontal displacements, which are usually to be observed in the mine-workings only.

Considering the earth-movements independently of the other effects, it is evident that two distinct sub-epochs are represented, the earlier displacement being an upheaval which tilted the strata of the Prescott region into a nearly vertical position, the later those resulting in a considerable horizontal thrust, perhaps at several successive intervals. The upturning of the strata was presumably the earliest effect, and the horizontal movements were, perhaps, prior to the intrusions, if the two were not coincident; for the igneous dikes are apparently unbroken, whereas the tilted strata are cross-fractured. However, I do not wish to argue this point without more knowledge, because there are features which might possibly bear a different interpretation. For all practical purposes, the resultant structure is more important than any consideration of genesis which does not limit the vein-phenomena.

In the area of greatest activity during this period there is a prevalence of slaty terranes at the surface; and this fact apparently has as much to do with the dominant type of vein-structure as the dynamic agencies themselves. The present position of the strata is not easy to interpret, although it really appears to require no explanation beyond the tension of a sub-jacent caldron of fused material, unless great lateral pressure or resistance, in opposition, may have been a potent factor.

I think we shall eventually find that the dynamic energy of this epoch was locally variable in direction as well as in intensity. Thus, while workers in the mines of the Prescott region will readily recognize the structure here indicated, they cannot expect always to duplicate their experience in other areas, even where the same agencies were effective. To illustrate, let us compare the geognosy of the Bradshaw mountains and their outliers, in Yavapai co., where the Peck, Gladiator, Crown King, Buster, Henrietta, McCabe, Little Jessie and other mines afford striking examples of the typical structure of this particular epoch, with the similar genetic conditions in the S. H. mountains, a small range in the Gila valley, Yuma co., which has been used in another place* as an example of a different type. In each instance the strike of the veins, the dikes and the upturned strata is alike through the local group, and the accompanying phenomena are similarly related; but the strike is NE-SW. in the former locality and NW-SE. in the latter. The dominant type in Yuma co. is that of the post-Carboniferous uplift, which is almost wholly obscured in Yavapai co. by the impress of the Cenozoic disturbance. Apparently the diminished intensity of the vulcanism in the region remote from the main outflows was overbalanced by the decreased resistance, allowing the escape of lavas, locally, through vents already provided by the earlier uplifts, and by denudation prior to this later epoch of uplift. We thus have the weak effects of this epoch constrained into lines marked out by earlier geologic events. The result becomes entirely a question of the relative influence of locality, as affecting the tension of the buried magma, and of resistance, as determined by prior dynamism and erosion. Our examples are chosen to represent fairly the extremes, but the field offers many gradations between the two, and probably beyond, in either direction.

The effects which characterize the later epoch, that of shearing, are more obscure. We know that they were subsequent to the formation of the main vein-system of the period, because the members have been subjected to shearing-strains which have produced horizontal displacements. The puzzle is to determine the exact relations of the parallel dikes to the veins and to the movement itself. Probably these elements can be determined, but, as yet, no one has seemed to appreciate the

* See p 1057

importance of the problem. I must confess much more ignorance upon the subject than is, perhaps, creditable; but it is more complicated than almost any other feature, both by reason of the lack of cues and because of the comparative weakness of the strains involved. The effects were most evident in the shales and slates, which afford the least permanent records. For the greater portion of our limited knowledge we must, perforce, rely upon underground developments in the mines; and these do not now furnish satisfactory replies to the most important queries. In Nevada, I have observed similar effects which were certainly produced in the subsequent Crater-period, and it may be that they are wrongly included here.

There is a common belief among miners and operators in the Prescott district that the veins are intimately associated with the dikes. It has always been assumed that the dikes antedated the veins; but upon what ground of evidence I have never been informed. The facts in many important illustrations do not seem to confirm this view.¹ But it is certain that the dikes and veins abound in the same areas, and to this extent they are mutually related. Leaving them both for later consideration, we may most conveniently examine now the dynamic results of the "shearing epoch," without committing ourselves fully to any chronologic order.

In the Prescott region, the district most typically affected by shearing-strains, the pronounced result has been a transferring to the westward of successive, vertically disposed units of fracture, resulting in their step-like arrangement. Since the epoch of shearing there has been no important vein-deposition in the cross-fissures produced at this time. In following the veins along the dip they suddenly "break off," as the miners say, and the continuation in depth is generally found by cross-cutting to the west, usually not many feet from the plane of the superior zone. Lack of appreciation of this well-determined fact led to serious litigation and unjust aspersions of personal character in the case of the Jersey Lily mine, at Jersey, Arizona. We have

* Let it be well understood that these remarks are exclusively applicable to the veins and dikes of this particular series. I am confident that later dikes, and possibly some of earlier date, have been more or less truly *vein-companions*; and that I may be wrong in questioning such genetic relationships here, is freely admitted, but my conclusions are drawn from hundreds of observations, and the evidence is cumulative also from later studies in Nevada.

encountered exactly similar physical conditions in developing a property (the Consolidated mines) in the neighborhood; and many non-resident engineers have been led astray through ignorance of this feature, which is recognized by all who have had local experience. A very good illustration of the horizontal thrust is apparent in the Blue Dick workings, east of Jersey, and many other examples might be cited from the region of the slaty environment. Again, this feature is reduplicated in many Nevada mines which I have recently examined. But there are many areal modifications, due to textural variations in the country-rock and, possibly, in some instances, to local differences in the intensity of the exciting cause. These conditions are more easily recorded than formulated, and yet the experienced miner can usually be trusted to work out the problem in individual cases, provided that he be left free to act. Engineering estimates made without due regard to this peculiar structure have frequently proved untrustworthy, because the surface-indications in the slates afford insufficient evidence of the nature of the substructure.* Eventually the engineer will acquire not only the miner's experience, but the knowledge which will enable him to interpret it more effectively in practical operations.

In the region farther west and south it is more difficult to distinguish the phenomena pertaining to the shearing epoch. Nevertheless, there is, in many veins, a very similar tendency to "bear off" eastward, at intervals, as development proceeds downwards. This is marked in the Elkhart, Schuylkill, Tennessee and other mines, at Chloride, Mohave co., although the strike of the strata and the trend of the veins have been but slightly modified from their attitude prior to the Cenozoic disturbances. The "break-off" condition is not apparent in these regions, †although I have observed something not unlike it in the Comobabi mountains, in southern Arizona, in veins of the post-Carboniferous series, and have had cause to suspect it in some workings in the Sierrita hills, both examples being from Pima

* Interesting examples are certain tunnels in Yavapai co., which did not reach the veins at the points predicted by very competent surveyors.

† Horizontal thrust along a fault of low inclination has carried the northern portion of the Elkhart vein 70 ft. to westward, as measured in the 2000-ft. level. This was not determined until after the distribution of the pamphlet edition of this paper, "Subject to revision."

co. It is difficult to realize that the crookedness of dip of these veins is due to the cause here suggested, but to attribute it to an agency coincident with the formation of the fissures is much more troublesome, in view of the present sinuosities in the line of strike. We are unable now to correlate these effects in widely separated districts; and it is possible that more attention has been given them here than they justly merit.

(b) *Intrusions*.—There is some doubt whether the shearing-strains have not actually affected the dikes, as well as the upturned strata and the veins; for many of the dikes are much shattered, although I do not know of any instance of actual horizontal disjoining accompanied by thrust. It is very difficult to explain the facts of existing structure upon any other supposition than that here announced; but we must for the present avoid committing ourselves irrevocably to the theory of a subsequent origin of the intrusive dikes. Possibly the act of intrusion may have produced the horizontal movement in the strata. The contents of the sheared veins is such as to lend confirmation to the idea of igneous movements prior to their deposition. The importance of having more facts has been brought home to the writer during the preparation of this paper, and more extended studies since its presentation to the Institute have emphasized the distinctions necessary to be made between basic and igneous dikes.

Viewed structurally, in the most general manner, it may be stated that there are three modes of expression of the phenomena which we here group together as presumably characteristic of one geologic epoch. If this view be correct, the differences are wholly attributable to local environment, for two forms of outcrop do not occur together in any area, so far as now known. This fact merely indicates a decadence of the tension beneath the surface over nearly the whole of Arizona, in this epoch, rendering possible the extrusion of the molten magma only in pre-formed vents. Thus, in the Prescott region, the lines of least resistance were coincident with the stratification of the upturned terranes; in the middle ground already described (Mohave co, in part, and elsewhere), the cross-fractures of the preceding period furnished the most ready exit, and the fault-fissures of like epochal relations were the only outlets suitable for the intrusions in the remote region to the

southwest, where the tension was comparatively weak. But in the regions of more intense volcanic activity, I have observed many instances of dike-trends which themselves dominate the geologic structure.

The intrusions have heretofore been referred to as "dikes," and the typical manifestation is an igneous stratum intruded between bed-planes of the tilted slates. These dikes frequently stand out prominently in the topography, as protruding walls, which can be traced for miles across country at one view, from almost any point in their outcrop. There are several of them of pronounced character, extending in parallel lines following the NE.-SW. strike through the heart of the Prescott region, and the most profitable mines of the district are more or less intimately related to one or the other, in position, if not in genesis.

Intrusions of this class well display the fissile structure due to lateral pressure, and their highly acidic character suggests, if it does not demonstrate, the fallibility of the theory of close relation in origin of veins and dikes. This last idea is strengthened by the non-occurrence of metallic ores in the dikes.*

But there are also in this region dikes not interbedded, but crossing the country. In districts where the post-Cretaceous fissures cut across the strike of the earlier terranes, in such a manner as to leave lines of inferior resistance approximately in the paths of the faults (other conditions being also favorable), there have been intrusive effects which differ essentially from the typical dikes above mentioned, and from others yet to be described. It is probable that limited outflows may have occurred in some of these instances, and we may be stretching the point in classifying the fissure-fillings as intrusions. But

* In my paper on "The Geology and Vein-Structure of SW Colorado," *Trans.*, xv, 218 (1886), I outlined a theory (developed from data collected by Baron von Richthofen, Dr. Joseph Le Conte and the writer, among others) which, in my opinion, fairly explains volcanic periodicity and the order of extrusion of basic and acidic lavas in the western United States. Referring to that paper, and to the writings of others therein quoted, for better elucidation of this subject, I may here remind the reader that acidic rocks, cooled from igneous fusion beneath highly siliceous terranes, indicate steady movement of the molten magma without commingling of the deeper-lying heavier ingredients. The source of the metals now included in the veins of this period is, therefore, most probably to be sought in pre-deposited ore-masses rather than in the deep-seated basic lavas then underlying.

they are conveniently discussed in this place; and their technical assignment is only important in making comparisons of separated areas.

Another feature of the "cross-strike dikes" merits attention. They are composed of *basic* material, and have frequently a strong tendency towards columnar structure. To a certain extent, it may be necessary to qualify our previous conclusions that the dikes have not had direct influence in bringing up the metals from below, so far as this particular set is concerned. But the caution which dictates this admission is based wholly upon theoretical considerations; for no practical demonstration has yet given any cause for treating these dikes as exceptions to the rule heretofore announced.*

This group of dikes represents the first stage of vulcanism in the region. The courses are not always strictly in line with the NW.-SE. strike of the fault-fissures, but they approach nearer to it than to any other neighboring geognostic feature. They are fairly persistent, but more local in distribution than the interbedded dikes. Very good examples occur on the western flanks of the Cerbat and Hualpai ranges in Mohave co., and other illustrations appear in some of the scattered ranges to the south and west; but the type is much less characteristic of Arizona than of tracts farther northeast.

A third class of dikes must be mentioned. In a limited way there is an expression of similar character to the interbedded dikes, in the region of outcrop of the ancient granitic rocks in southwest Arizona. Roughly speaking, the effects are graded in diminishing importance as we proceed westward, but the complications brought about by the outflows of a later period, and possibly by some contemporary effusions, have rendered generalization unsatisfactory without more knowledge of details than we now possess. I venture the opinion that both basic and acidic material have been concerned in the filling of the fault-fissures which these dikes ordinarily occupy or closely

* See the paper quoted in the preceding foot-note for further elucidation of this subject, with illustrations from a region of greater activity. In Humboldt county, Nevada, in a district where the NE. copper-vein trend is eminent and where the crater-effects are relatively weak, as compared with the results in White Pine county, the indications imply that the dikes were chiefly produced as late as the Crater-period.

parallel. The members of this series occupy a position between the groups before described in some such way as this. The interbedded group, in trend, structure, texture and mineral composition, has been largely coerced by stratigraphic environment, whereas the cross-strike group, in all these particulars, has been chiefly dependent upon the weak resistance offered by local fractures and a thinner crust. The fault-line group is coerced in trend and structure very largely by the pre-existent fractures, and the texture and mineral composition are much dependent upon the stratigraphy of the locality. Beyond this it is best not to go until we can tread on firmer ground. Illustrations are abundant, but only a few need be adduced here. In the Baboquivari mountains, the Coyote mountains, and the small ranges farther west, as the Comobabi, Silver Bell, Owl Head, Picacho and others, in Pima and Pinal cos, these dikes have not resisted wear to such an extent as to completely define the topography in opposition to the erosive agencies. But in the low ranges in Yuma co., the Eagle Tail mts, the S. H. range, King mountains and others, the dikes have constrained the topographic outlines most rigidly. The former area contains the more basic dikes, the latter the more acidic. I do not say that this is strictly true of the outpoured lavas, for they represent a different period.

Under this head may be named also an interesting set of quartz outcrops which closely follow the NE-SW strike in the Prescott region. They are less regular and more interrupted than the typical interbedded dikes. Most geologists would reject the title of "dike" in this connection, but it is commonly applied to them locally by the miners, and there seems to be no better place to introduce them in this discussion.* As nearly as can now be determined, these quartzose walls appear

* It is deplorable that there is such loose employment of this term, not only by miners, but by engineers and geologists. In a glossary which fairly represents the average miners' parlance, I find the following definitions:

"DIKE—A fissure made and filled by plutonic action. Its rock is most commonly porphyry. It is often barren but in some cases mineralized, or may carry a mineralized selvage and so appear as the wall of a lode."

"DYKE—A wall-like mass of mineral foreign to the general formation."

In conversation with a prominent foreign mining engineer upon the subject of these same quartz-reefs, which he had examined, he remarked, "They are not dikes, because they do not cut across the veins."

to be but another expression of the same energy which produced the igneous dikes, or, rather, it may be supposed that they are due to similar causes modified by special environment. There is apparently a much closer alliance of the veins with these reefs than with the real dikes. In fact it is often difficult to separate the "reefs" from the category of veins. The only criterion I have found useful is that of the mineral inclusions, and this is not wholly satisfactory.

In the district east of Mayer, in Yavapai co., some copper-ores have been taken almost directly from these outcrops, and certain veins yielding much copper are very closely related to the reefs in position. So far as my own studies go, it is not very difficult to distinguish the reefs from the veins, even when the latter are decidedly quartzose, but the development of properties in the vicinity of the reefs requires the exercise of judgment and skill. Farther west in the Hassayampa country there is less chance of confusion, perhaps, because the outcrops of the reefs are much less frequent.

The only mineral I have detected in the matrix of the quartz reefs is lamellar magnetite. The "copper stain," sometimes formed in crevices of the broken quartz, is invariably of extraneous origin. The quartz is usually amorphous or cryptocrystalline, and the magnetite is disposed in thin plates, forming a more or less regular network through the mass. Occasionally considerable blocks of ore may occur upon one or both sides of the reef, as in the Little Wonder and Bonanza King mines, at Jersey, and a similar exposure known as Bald Butte, on Mint creek, has very prominent outcrops of rich gold-bearing "honeycomb-quartz," appearing at intervals as wedges between the walls of the reef.

This class of intrusions (if such they be) deserves very careful study. The Zero mine, the Quartz Mountain mines and many others of similar environment in the Hassayampa drainage-basin, in Yavapai co., are closely dependent upon the interrelations of the reefs and veins. The conditions seem to favor the occurrence of the ores in "bonanzas;" and this may account for the great richness of the ore-shoots in places.

(c.) *Ejections*.—We enter a little-worked field when we take up the discussion of the volcanic outflows. There is nothing in the history of the epoch preceding the main eruptions which

can be said to have an important bearing upon the vein structure; but the presence or absence of a capping might have had much influence upon mineral segregation locally.

An illustration of moderate local outflow has been given in another place.* It is probable that some outpouring occurred in many districts where we now have but little evidence remaining; but some of the prominent topographic landmarks, with cappings of lava resting unconformably upon the substructure, are presumably traceable to this epoch. Of this nature I now consider the basal portions of the lava-flows in the Superstition mountains, east of Phoenix, and many of the outcrops of similar nature in the Pinal mountains around Globe, as well as isolated exposures all over the country to the west, north and south. Without going further into the subject, it may be stated roughly that the eruptives of this class are more or less basic, varying somewhat in composition and texture in accordance with the stratigraphic environment. The effects produced in the Santa Rita, Huachuca, Chiricahua, Peloncillo, Graham, Gila, Mazatzal and other ranges eastward, have not been segregated in detail from those of a later epoch, but good sections are available in the San Pedro cañon, east of Tucson, and in numerous other localities, where erosion has clearly exposed the dual character of the volcanic history. Very good illustrations are outcrops in Hackberry cañon and Mineral creek and other portions of the Gila drainage, in Pinal co.; also near Dripping Spring and Pioneer, in Gila co., and there are others in the cañons tributary to the Salt river, in Maricopa co.

(d.) *Vein-Structure and Texture.*—I have attempted to make clear one salient principle which is practically applied by all successful miners in the Prescott region, although they may not recognize it in terms, namely, that there are four classes of rock (the interbedded, the cross-strike and the fault-line dikes, and the quartz-reefs) to be considered in every mining problem in the area of NE.-SW. trend. A fifth (the volcanic capping) may be present, but it cannot be confounded with any of the others. It may be that neither the igneous dike nor the quartz-reef will interfere with the working of the vein, and neither

* See footnote, p 1057

need necessarily become an adjunct of favorable importance. Vein and country-rock will require particular attention at the start. But, as a preliminary step, the operator needs to know whether he is tackling a real vein, or merely a quartz-reef or an igneous dike, but it is very important also to determine whether the vein is intimately associated with the dike or reef, when close at hand. These questions once settled, the vein and its "country" demand careful investigation.

The country-rock is usually slaty or shaly, which renders prospecting difficult, for the vein-outerops are often obscured by the detrital deposits and the "float" often yields uncertain indications, because it may be visible only in spots where the ground has been washed away, and it may be covered where the same influence has deposited earth around it. Thus it frequently becomes necessary to sink test-pits at many points before the ore-bodies can be traced. Another hindrance is the false evidence sometimes afforded by oxide streaks, which ramify abundantly in the bed-plane crevices, often staining the slates themselves into the semblance of real veins. Even the test of assays from surface-exposures may deceive, because it often happens that the richer veins have been leached in the exterior zone to a measurable depth. Again, the concurrent testimony of all ordinary tests, if affirmative of the vein character, cannot always be taken as proof of the *locus* of the main shoot.

As is well understood, veins enclosed in slaty "country," where the rock is friable at the surface, are very liable to be split up into several branches in the oxidized zone; and although almost any one of the branches, if closely followed, would eventually lead to the main body, there are vital legal questions involved in the priority of location. It is, therefore, not always safe in this district to work a property which has not unusually broad surface-ground. The width of one claim (600 ft.) is certainly ample in most cases, if one be sure of his rights, with the vein in the median line. But this often presupposes knowledge which comes only from deep working. This uncertainty explains the common custom of large holdings, much ridiculed by some non-residents who lack local experience.

Really there is not much difference in the veins of this group

from what will be recognized as characteristic of any locality in which the slates predominate, except that here the effects have been extraordinary in amount. The structural features, while conforming closely to pre-existent geognostic lines, are apparently very much more affected by lithologic environment. Perhaps this proposition is less applicable below the zone of oxidation; and even greater influence may be justly attributed to variations in the deeper-seated sources of supply of the vein ingredients

The walls are well or ill defined according to the rigidity of the "country" at the point of contact with the vein. It is very common to find the slates themselves impregnated heavily with the ores in surface-exposures, and cross-cutting often reveals unexpected ore-masses in the deeper workings. The texture of the veins varies greatly; and the mineral contents do not appear to bear any close relation to this feature, except in a restricted sense. That is to say, one cannot judge of the amount or quality of the contained mineral from simple examination of the matrix, although it is usually possible for the local expert to detect the richest portion of individual claims after a little experience. But it frequently happens that one property will manifest its richness, especially as regards gold, in a kind of vein-matter which is barren in neighboring mines, notwithstanding the fact that the latter may carry equivalent values in a different matrix. Again, each particular district has its own *general* mode of occurrence of the ores. Consequently there are few tracts where non-resident examiners are so liable to err in estimating the true value of an investment.

(e.) *Distribution of Vein-Materials.*—It is a question worth studying whether the irregularities in distribution of the vein-components are wholly erratic, or if they may be brought into harmony with any system of arrangement which can be depended upon as a practical guide.

Near Jersey, Yavapai co., the Fred Smith and the Ross claims lie parallel, about 1800 ft. or more apart, and the rich outcrops are not at opposite points, but are separated by about half a mile, measured along the vein. The gold-values are contained in a dark "honeycomb"-rock, which is abundant in both veins for long distances, and is also characteristic of many other vein-outcrops

in the neighborhood. This rock runs well in gold in a portion of the Gold Jem claim in the line of the outcrop of the Fred Smith; but in the Scotland, a parallel claim, and in portions of the Bonanza King and other claims opposite the Ross, the same class of material is practically barren.

In the Jersey Lily mine, lying between the Ross and Fred Smith veins, the rich ore near the surface was contained in honeycomb-quartz, in part; but the color and texture were not the same as in the other cases. The Fred Smith ore appears more like "worm-eaten" rock, and the Ross quartz is similar, with more tendency to the Jersey Lily texture within. In one part of the Gold Jem a porous earthy quartz is gold-bearing; but a very similar substance is absolutely barren in a parallel claim. The rich gold-ore below water-level in the Jersey Lily mine is a massive pyrite of dull luster and by no means brassy. A similar mineral in the Blue Dick mine, one mile eastward, runs low in gold, whereas the accompanying "brassy pyrite" is highly charged with this metal. But the Blue Dick is not as good an example of the veins of this period, having been strongly influenced by earlier deposition.

In the district surrounding Mayer there is a similar manifestation, and a further specialization is prominently indicated, which is only hinted at in the Jersey region. Here the veins of copper and of gold are remarkably distinct. Not only are the copper-belts well defined and separated from the auriferous tracts, as a whole, but there are some very interesting examples of similar segregation within one and the same narrow belt. Thus, on the Mineral Hill and Examiner claims, at Huron, lying parallel, in a tract between the great gold-belt and the main copper-belt of the district, there are several parallel vein-outcrops in which the gold- and copper-ores are separated in irregular alternation. Though not very explicit, and apparently paradoxical, the statement that copper is not usually abundant in the gold-ores, whereas gold is prevalent in the copper-ores, will be well understood and affirmed by workers in the region. It appears that gold has not been as particular in its passage upwards as copper.* Two veins, 10 feet apart, which were

* This is in line with the outcome of experiments on vein-formation made by the writer and alluded to under II, 2 (d), *ante* (See footnote, p. 1061)

cross-cut in a tunnel on the Mineral Hill claim, gave samples (each covering 3 feet in width) as follows

	Gold Oz per ton	Silver Oz per ton	Copper Per cent
No 1,	0 15	1 20	trace
No 2,	0 70	1 10	trace

A third vein near the boundary between the Mineral Hill and Examiner claims yielded

	Gold Oz per ton	Silver Oz per ton	Copper Per cent
No 3,	0 20	1 40	1.45

(Nos. 1, 2 and 3 would be classed as gold-ores.)

Two samples from a shaft on the Examiner claim gave:

	Gold Oz per ton	Silver Oz per ton	Copper Per cent
No. 4, from bottom of shaft,	0 80	3 40	9.25
No 5, " shaft 10 ft. below surface, .	0 50	2 40	21 45

(Nos. 4 and 5 would be regarded as copper-ores running well in gold.)

In a drift on the Mineral Hill, at a point on the vein about 50 ft. below No. 2, above, we have recently encountered the ore-shoot, from which a sample yielded .

	Gold Oz per ton	Silver Oz per ton	Copper Per cent
No 6,	1 12	33 90	5 80

Three samples taken by myself from the Buster, a distinctive copper-mine directly in the copper-belt of the vicinity, yielded from a trace of gold to a maximum of 0 40 oz. per ton. These yielded copper as below

	Copper Per cent
No. 6, five feet width of face, NE drift from tunnel, . . .	6.80
No. 7, ore streaks of above, partly cleaned, . . .	8 84
No 8, ore partially assorted, . . .	10 60

The copper-ores of the Bullard mine, 25 miles west of Congress, carry about \$13 to the ton in gold

The foregoing examples are all typical, but not by any means exhaustive.

Nearly all the copper-mines of this series of veins carry gold in appreciable amount; but the gold-mines, which have pro-

duced an enormous aggregate of the precious metal, are very rarely cupriferous. This is diametrically the opposite of the distribution of these two metals in the earlier vein-series; and the difference in this respect between the Copper Queen and Old Dominion mines and the mines at Jerome is partly of this character. But there is another influence which must not be overlooked—the relations to the auriferous vein-series, or system, of E.-W. axes.

Lynx Creek mines illustrate the same peculiarities, and the region of the Bradshaw mountains affords numerous instances in keeping with the principle here enunciated. Some of the most prominent gold-producers all over the district exhibit features which would utterly condemn them as representatives of the preceding period. Hence it is a matter of great importance to determine to which series a given vein belongs before passing judgment upon its value; and it requires much practical experience in the area itself to enable one to speak with authority on this point.

The cause of this remarkable difference in segregation in the two periods of geologic time is not to be detected at a glance. The facts themselves have not been clearly recognized by workers in the field, and it is, therefore, not strange that no one has heretofore attempted to explain them. To my mind, the whole difficulty disappears when we regard the later series of vein-fillings as mainly due to the transfer of material by aqueous agents from the previously deposited veins of the earlier series. A part of the evidence is before the reader of this paper, much more will appear upon acquiring some familiarity with the district, and a careful study of the subject will bring to light a preponderating array of facts which do not admit of any other conclusion.

In discussing minor details one is most liable to generalize from insufficient data. Let it be borne in mind that two or more classes of veins are liable to occur together in nearly every district in Arizona. We are dealing just here with only one class—the typical veins of the northeast trend. The hard and fast lines we must perforce draw in our classifications cannot always be established to a nicety in individual cases. Moreover the theory here advanced itself calls for many local variations in the mass and quality of the ore-bodies. Hence the

necessity for great caution in interpreting the indications observed in the mines of the Prescott district.

Those who have given most attention to these veins will probably agree with me in the statement that the positions of ore-bodies are much less influenced by proximate local environment than by the *loci* of pre-formed bonanzas from which they are derived. Consequently a knowledge of geologic structure is even more advantageous than an intimate acquaintance with the country-rock and the vein-fillings

Another point of much significance is the variety in the modes of occurrence of gold in the oxidized zone. Aside from the fact already announced that the free gold does not invariably appear in vein-matter of given character, it also occurs at times in peculiar situations where the only semblance of vein-structure is an oxidized stain or an earthy deposit of uncertain relations. These manifestations merely indicate that conditions have supervened since the original vein formation which have permitted distribution of the oxidized products along new lines near the surface, but the importance of such considerations cannot be overlooked in practice. The stock in trade of the best guides to development in the region is, therefore, a well-equipped storehouse of facts gathered in extensive local experience.

Much evidence might be adduced in support of the conclusion that the main source of the gold in this vein-series is really to be sought in the ancient east-west auriferous belts hereinbefore described, and that the copper-ores have come chiefly from the northwest-southeast belts of earlier date. Bearing this idea in mind, we may roughly circumscribe the areas of maximum mineralization, and also gain a valuable means of determining the localities most favorably disposed for mining

To explain more fully, if one has traced out the true course of a prominent ore-belt of the auriferous series, the continuation of its trend (E.-W.) across this track will be presumably the richest part of the field in gold-values. With modifications already catalogued, the same rule will apply here as in the case of the bonanzas of the NW.-SE. trend. For copper, other things equal, near approach to deposits of the NE. trend will be the most favorable indication; but, naturally, this test will usually be more difficult of application

It is a fact that the best parts of the gold-fields of the Prescott region are those which lie approximately east of the principal free-gold camps of the denuded area of western Arizona, and it is very true that all the copper-deposits now worked in the Prescott field can be duly arranged in NW.-SE lines which will individually express more or less independent characteristics, although their relations to the NE-SW. course are very close. In Nevada, the connection with the NW. course is not evident, as a rule, but the copper trend is distinctively NE.

We shall not be able to discuss these interesting features more extensively in this paper, but the data available afford very striking proof of the theories of origin here announced

(f.) *Vein-Contents*—The oxidized minerals of this series of veins do not require specific mention here, although there is undoubtedly a most prolific field for chemical investigation in the relations of these to similar products of other vein-classes. I have never been able to identify any but the common oxides of iron and copper, with their usual salts (carbonates and sulphates), in this present group, and I think it safe to deny the existence of chlorides as well. At the same time, we have not followed home the very interesting occurrence of ores of vanadium and other rare metals. One deposit of vanadinite in this district, in connection with abundant manganese-ore and rich silver-minerals, is noteworthy. The Silver Belt mine, and especially the Lincoln mines, in the same neighborhood, carry large quantities of vanadinite associated with rich silver-ores. This fact and the occurrence of a similar quality of vanadinite in close connection with copper-ores in a tract south of the Mammoth mine, in Pinal co., and its association at this mine with a lead-compound (wulfenite), gives much support to the notion of an origin subsequent to the deposition of the veins of NW. trend. The presence of gold in quantity in such shape as at the Mammoth does not militate against the theory, whereas all facts known to me now tend greatly to strengthen it. The occurrence of tellurium in Yuma co., near Harrisburg, is in a district where the NE. trend of uplift is evident.*

* This subject has already been more fully treated above (pp. 1062, 1063). There is here a fertile field for investigation by the chemical geologist. I can only adduce facts to prove ignorance.

Gold occurs free in a zone which has been oxidized to the depth of about 150 ft., as a rule, irrespective of the topographic outlines. The area is generally considered a part of the arid region, and at times the surface is very dry for months at a time; but it is subject at irregular intervals to very heavy storms, which excessively wash the surface, often leaching or abrading the exterior portion of the veins. Below this "weathered" zone, which varies greatly in extent, the ore-bodies are usually concentrated to within 50 ft. or more of the permanent water-level. Between 100 and 150 ft. from the surface there is frequently a barren zone, the sulphide-ores appearing at or near the water-level. Veins in quartz are not always oxidized to as great an extent as here noted. The free gold is usually fine-grained, often invisible to the naked eye. Owing to its erratic manifestations in this class of veins many serious errors have been made by engineers reporting on properties in the district without detailed study of the veins. There are instances where the so-called vein-walls are several feet apart, whereas the real vein-components occupy but a small portion of the width. A property with an ore-body of 2 ft., sampling \$10 per ton in gold, would be regarded as a fair business proposition, but if a well-known expert should include 8 ft. in his sample, the extra width being barren, his average of \$2 50 per ton would become the basis of a condemnatory report. On the contrary, the concentration of gold in the gossan of veins of this class may lead to unwarranted favorable conclusions. The best evidences of value are usually obtainable below the depth of 150 ft., in the sulphide zone, but the means of judging fairly are not necessarily thus limited to one who is well acquainted with the district.

Pyrite occurs in a different mode, in these veins, from its exhibition in the earlier vein-series. Here the coarse crystals, in massive aggregations of dull luster, appear to be the auriferous vehicles *par excellence*. The granular crumbling masses, made up of minute crystals, are rarely gold-bearing. The most valuable deposits are imbedded in a white quartz matrix, and occasionally large crystals of galena are associated with the pyrite, but lead-ores are not characteristic of this vein series. Car-loads of the pyritous ores have been shipped from the Little Jessie, McCabe, Jersey Lily and other mines on the

typical veins, which have yielded from 10 oz to 30 oz. of gold per ton.

Chalcopyrite is not as frequent a constituent of the distinctive gold-veins as might be inferred from the foregoing statements. The facts seem to hint of double lines of genesis for the gold- and copper-veins of the period. This may be as much due to separation of the sources of supply, geographically, as to any inherent cause connected with the deposition of the minerals, although the conditions heretofore described near Huron Station do not strongly fortify this assumption.

The copper-veins of this group present very similar conditions, except as to mineral-contents. The gangue is much the same as that of the gold-veins, but the absence of lead-ores and of non-cupriferous pyrite is very noticeable.

A district in southern Arizona and northern Sonora appears to be affected decidedly by this line of disturbance. It is here that the "mixed ores" occur most commonly, and the apparent anomalies already discussed in the preceding division are cases in point*. Zinc is not characteristic of this series, but my present impression is that arsenic belongs distinctively to this vein type, as the ores of the Hillside and Cherry Creek districts, in Yavapai co., are examples of such composition. Arsenic may be wholly of later origin, however.

4 *The Post-Tertiary Crater-Eruptions.*

It is presumable that the somewhat localized disturbing effects, which were subsequent to the period of general volcanic activity in the western United States, have involved the Tertiary strata. The importance of this feature in its bearing upon the petroleum-industry is not to be gainsaid, and the necessity for holding it as a working-guide in much of the region west of the Colorado is very apparent. Some recently discovered oil-indications in western Arizona suggest a similar caution, but otherwise the mere stratigraphic relations of the crater-eruptions do not appear to have a very important bearing upon structure or vein-formation.

The geographic extent of the eruptions is not restricted, but there are differences in the effects in different areas, due mainly

* See p 1062

to local variations in the tension and in the resistance offered at the *loci* of ejection. The subsequent vein-deposits, it will readily be understood, are greatly dependent upon both these factors and also upon the conditions of the resultant structure, as well as the accessibility of earlier mineral aggregations

The recognizable remnants of important craters do not at first sight appear to have any system of distribution, but one cannot long work over the field without being impressed with the tendency towards alignment in two directions. Individual differences in amount of lava-flow and in subsequent erosion have left the topography much more irregular than the geology would indicate, if diagrammatically represented. That is to say, the crater-cones, large and small, were actually distributed, in semblance to quincunx order, along the previous lines of weakness of the two next preceding uplifts—on the fault-lines of the NW.-SE. trend more especially, but to some extent also in the path of the later NE.-SW uplift. By far the greater importance must be attached to the vents afforded by the northwest fault-fissures, and this fact explains very much of economic interest regarding the character and distribution of the ore-deposits of the crater-veins. These features are strikingly exhibited on the map accompanying this paper

The lava-flows and other proximate products of eruption,—such as vitreous, scoriaceous, tufaceous and ashy materials,—are illustrated in great variety, but there are two features which have much practical significance in mining, namely, the extent of disruption and the amount of secondary action. Without attempting more than a very general application, it is possible to enunciate a law which will serve as a fair index in many cases. Other things being equal, the vein-deposits of this epoch are roughly proportional, qualitatively and quantitatively, to the dynamic energy. This is not saying that the resultant of energy *versus* resistance is the measure of the impress of this vein-series upon given localities. It simply means that one must expect to find complications in structure and in vein-contents due to this period of vulcanism in nearly direct ratio to the tension of the magma at the focus of eruption of the individual craters. But the mineral segregations due to secondary action will depend largely upon the relations of the crater-period fractures to the earlier veins which constitute the

source of supply. These deductions gain force from the Nevada region, where the same conditions are intensified by maximum crater activity

We have abundant evidence that the conditions of vein-formation, when the fissures of this epoch were filled, had undergone a change since the period of the preceding "mixed ore" deposition, for the products are wholly different and of a character showing selective segregation. This result cannot be explained by any fact of distribution of the earlier vein-ingredients, it must have been due to chemical reactions which were powerless to modify the gold-ores, but very effective in transforming and transporting the silver-compounds

(a) *Vein-Structure and Texture*.—There is no distinctive trend characterizing the veins of this period, and their detection is rendered more difficult by reason of what might be termed the pseudomorphic character of some examples. In other words, where the lines of least resistance were prior structural vents, as bed-planes or fracture-courses, or where these have subsequently acted as channels for the vapors and heated waters, veins of this series have occasionally been produced in such a manner as to simulate closely one or other of the earlier sets. The most common type of this class is probably the E.-W. pseudomorph, but I am familiar also with examples of the NE.-SW. trend; and there are suspicions concerning some which, in certain localities, fill fissures trending NW.-SE.

The veins of this period are more confusing than any others, viewed solely by themselves; but there are two features by means of which they can always be distinguished from other series (1) they are never broken by other veins, but have invariably broken any which they cross; and (2) their mineral contents are different. The dislocations which have occurred since the formation of the crater-veins do not contradict this last statement, but they have caused complications which, though commonly of mere local import, may give trouble in mining if not rightly diagnosed. Two or three instances of this have already occurred in one district; and greater pecuniary losses are liable to follow from lack of appreciation of the structural conditions here explained.

Another element of complication in practice is the frequent ramification of the veins, especially as interbedded contacts,

through the more superficial terranes. Accurate surveys and close watch over developments by skilled engineers are essential to success with such properties, as is plainly evidenced by the experience of operators in localities where such deposits occur. It goes without saying that the effects produced upon the older veins by the dynamic agents of the crater-period only serve to add to the puzzles which must be worked out in mining.

Taking this class of veins in local groups, it is usually possible to trace them all to a central focus, or radiating point, which is the site of an ancient crater. But there are two reasons why the outcrops are commonly less distinct, and the tracing consequently more difficult, than in the case of earlier veins. The cap of lava or other material which has been requisite for vein-formation has not been so largely eroded from this late series; and the segregations have been formed chiefly at or near the intersections of earlier veins, thus often making the bonanzas of this epoch better indicators of earlier vein-courses than of their own fissure-trends. Therefore not a little of our knowledge of this last series must be gained from mine-workings, a fact which may excuse the ignorance we cannot but confess.

The texture of the veins of this order is usually specialized enough to enable one to distinguish them from the older groups, and the recent displacements have produced unique effects. The results of kaolinization are markedly apparent, and the matrix is very fine-grained, or saccharoidal. The contained minerals are likewise micro-crystalline in texture. Included masses of amorphous or crypto-crystalline quartz, approaching porcelanic sintery types, are not infrequent. In fact, the whole appearance indicates a formation more recent than that of the other veins of the region, with abundant traces of the action of heated waters, solfataras and other concomitants of the last stages of vulcanism.

My illustrations in detail are largely drawn from the Chloride district, Mohave co., but the White Hills mines in the same county afford even more striking examples; and abundant evidences of the same structural and textural features may be gleaned from all over Arizona and the adjacent regions. Recent developments in the Yaeger mines, in Yavapai co., confirm in the most convincing manner the proposition here announced. In Nevada, this crater system is especially prominent.

(b.) *Vein-Contents.*—The true silver-minerals are characteristic of this vein-type, and it is remarkable that silver sulphides are abundant in situations where the active solvents apparently had free access to stores of gold and copper without materially altering the pre-existing compounds of these metals. This fact may partly explain the deposition of the minerals now contained in the matrix of the crater-veins, as it implies the factor of sulphurous fumes or solutions, which might, perhaps, have little alterative effect upon pre-formed sulphides carrying gold and copper.

But there are also important local deposits of copper-ores that seem now to belong to this epoch of vein-formation. Of these, possibly, the United Verde mine is in part an example. My studies thus far leave me in some doubt, but I am disposed to regard these deposits as not exceptional, and as due to the action of excessive heat. In other words, near the centers of eruption, especially in conjunction with pre-formed masses of rich copper-ores, there is liable to be some departure from the typical products of this series. It is a very significant fact that, in every case of this kind which has come to my notice, there is very close relation to the NW.-SE. series of veins. A very interesting additional observation is the apparent absence of ores of lead, even from situations where access to such material was not restricted. This may, perhaps, be explained by the relative specific gravities of copper and lead sulphides; but the whole subject of the proximate distribution of lead and copper in the region is but beginning to be understood.

In this connection we must consider some interesting occurrences of native gold, silver and copper, to which allusion has already been made in this paper.* On Lynx creek, Yavapai co., a mine formerly worked by Mr. Willard S. Morse has yielded some very peculiar gold-segregations. Judging from descriptions of the run of ore,† and from a fair knowledge of the district, it seems probable that the impress of the NW.-SE. and NE.-SW. trends are here evident, with, perhaps, the secondary action induced by the crater-type of structure, but these opinions have not been actually verified. The specimens

* See p 1062, above

† Morse, "Milling Arizona Gold-Ores," etc *Trans*, xxv, 131 (1895).

shown me by Mr. Morse were very similar to a part of the early products of the Ray mine, Pinal co., except that the gold on Lynx creek was "tangled" through the quartz in large flakes, whereas native copper occurs in the same manner in the Mineral Creek district (Ray mines, etc.). Some remarkable deposits of native silver, as at the Buckeye mine and other mines near Mineral Park, Mohave co., may have had similar origin. The occurrence of "leaf silver" in porphyry at Globe and Bisbee illustrates equivalent features. At the same time, the possibility of direct igneous action in all these cases is not to be denied; but the presumption is in favor of this Crater-period as the date of formation. We have yet very much to learn of these matters, and the few facts gleaned only emphasize the need of more detailed study of the veins and their environment.

The very high-grade silver-ores, sulphides and chlorides, which gave intense but short-lived prestige to Tombstone, in Cochise co., Silver King, in Pinal co., Pioneer, in Gila co., McCracken, in Mohave co., and many other examples of greater or less fame, such as certain mines at Harshaw, Santa Cruz co.; Qujotoa, Pima co., Owl's Head, Pinal co., many once famous silver-producers in Yavapai co., and at Chloride, Mineral Park and the White Hills, Mohave co., are apparently all illustrations of local segregations of this crater-type. They are not as safe for the investment of large sums as the lower-grade continuous deposits of earlier origin, but they have the merit of not requiring heavy outlay until their extent has been proved, because their ores are usually rich enough to ship without more than ordinary hand-sorting.

"Ruby-silver," "grey copper" and "horn-silver," in miners' parlance, comprise the bulk of the common minerals of this series, but the technical varieties are numerous. Proustite and cerargyrite are common, but a long list of complex sulphides might be made up from the different localities, showing departure from the type-species according to the relative degrees of admixture with accessory metallic ingredients. Antimonial varieties are probably most abundant, but arsenic is prevalent in a belt of uncertain limits in central Arizona. Copper and zinc in abnormal proportions are occasional, as at the Altata and neighboring mines in the Chloride district.

III. REVIEW OF THE STRATIGRAPHY, AND ITS ECONOMIC RELATIONS.

There is a wide field for investigation of the details of the geologic record, and only the most general outline can be given here. Over much of the Territory no systematic work has been attempted. The only investigations conducted at public expense have been carried on by the U. S. Geological Survey and, for a very short season, by Professor John F. Blandy, as Territorial Geologist, with disconnected studies under the auspices of the University by myself, as Director of the School of Mines, and later by Professor William P. Blake, in the same capacity. Naturally the published results have been less explicit in stratigraphic details than in other directions.

1. *The Archean Granites.*

A rough classification of the granitic exposures into two classes, namely, the massive and the fissile, may serve as well as any scheme to cover our ignorance of the real relations. There seems to be some little warrant for regarding the former group as antecedent in origin, but this may not be true of all the outcrops. The present position of the exposed masses is probably due not so much to simple erosion as to orographic processes subsequent to the solidification of the mass.

(a) *Massive Granites.*—Even the best examples of what appear to be ancient granite bosses have been considerably shattered by the more recent dynamic events, so that it is often difficult to separate them from the typical fissile granites, presumably of later date. The distinguishing features are brought out more clearly by weathering, and the texture is usually also characteristic. Another distinguishing point is the general absence of veins of the standard fissure-courses. The masses of this class are exposed in the somewhat restricted "barren belts," of which a limited tract surrounding Prescott, and including Granite mountain, is a good example. Apparently this was brought to light chiefly by the uplift which resulted in the NE.-SW. trend, although subsequent erosion may have enlarged the exposure of it in the outlying edges of the field. Other examples, presumably of similar origin, occur farther southwest. In a portion of the Grand Cañon of the Colorado, in northern Arizona, there are exposures of such granite due to

erosion, and it is probable that some similar outcrops occur in the valley of the Colorado, in Yuma co., and in California. The outcrops of the Little Dragoon mountains, Cochise co., present very similar features, and like indications of the epoch of uplift which brought the granites to light.

Aside from the granites of this series fit for building material, the occurrences of other minerals have been little investigated. Mica has been reported in commercially important dimensions and quantity, but no practical results have followed attempts at exploitation. The source of the limited finds of platinum in the lower end of the Grand Cañon of the Colorado has not been ascertained, but there is at least a suspicion that this metal may have been associated with the basal granites. Several competent authorities have detected platinum in varying proportions, but as yet it has not been possible to locate the original outcrops *

(b.) *Fissile Granites*—There is an important series of granitic rocks which appears to lie between the massive granites and the schistose strata which form the floor of much of the area in western Arizona. These are, of course, involved in the successive uplifts, but they show most plainly in two of the trends—the E.-W. and the NE.-SW. In southwestern Arizona, and to some extent farther east, they are prominent as interstratified portions of the terranes of E.-W. strike; in the Little Dragoon hills and in the outlying portions of the Granite mountain country about Prescott, they are largely involved in the NE.-SW. strike. The members of this series are usually fine-grained, without massive structure, although some of the layers are of considerable thickness. They have the appearance of metamorphic granites, with distinct bed-planes. Some of the basal members are veritable gneisses.

The minerals of economic importance which seem to be related directly to the fissile granites are not numerous. Possibly some reported asbestos may be within this terrane, and it may be that the platinum thus far discovered is really to be

* This information comes from a reliable source, but it may be that the material in which the metal was detected was not actually collected by the person making the test. I think, however, that Mr. Herman Poole, of 327 Canal St., New York City, has verified the discovery by analysis of his own samples taken on the spot.

included here, but these assignments are very questionable. Some of the free-gold veins of the E.-W. auriferous series are interbedded, with granite-schistose contacts. This is especially marked in southern Arizona, in Pima co, south of Tucson. Apparently of much later origin, but similarly associated (or more directly in the granitic belt) in the NE.-SW trend, are the recently discovered outcrops of tungsten-ores (wolframite and hübnerite) in quartz. Probably these owe their position as much, or more, to igneous action subsequent to the metamorphism and upheaval of the granites.

As to the age of the granites, we can only estimate roughly the geologic epoch represented by these rocks. In the Grand Cañon section, as early announced by the U. S Geological Survey, Cambrian and pre-Cambrian strata are exposed; and it is very probable that all the fundamental granites of Arizona are pre-Cambrian. Their stratigraphic characteristics have never been thoroughly studied. There is, in some exposures, a suggestion of similar history to the outcrops of Archean type in Texas, Indian Territory, Arkansas and Lake Superior, but other facts seem to militate against this hypothesis. The doubt can easily be dispelled by more detailed study.

2 *Schists, Slates and Slaty Shales*

There are, possibly, rude lines of separation between the schists, slates and slaty shales, and our present inability to classify them is probably due to the imperfect state of our knowledge only. Whether any portion of the schists is pre-Cambrian I am not prepared to decide, nor can it be confidently stated where the Cambrian strata run out at the top of the section. Such facts as are accessible strongly indicate a complex stratigraphy, with a certain thickness of schistose members, of possibly pre-Cambrian date, overlain conformably by Cambrian slates, and these again covered conformably by Silurian members, largely shaly. This is a confessedly rough classification, and designedly so. Such study as I have been able to give the matter has led to the conclusion that further complications by shore-lines and local deposition have made generalization very unsafe without the comparison of many sections and the collection of a vast array of evidence from all parts of the Territory.

The structure, in the main, comports so well with that of the better-known regions beyond, that we may well hesitate to accept as final the orographic limitations of the preceding portion of this paper. There may be evidences of disturbance prior to the close of the Paleozoic age, but such effects have not been recognized as yet by those who have investigated chiefly for economical purposes.*

(a.) *The Pre-Cambrian (?) Schists.*—The schistose series is well exposed in northwestern Arizona, in Mohave co., with E.-W. strike, tilted at high angles. Very similar exposures occur in other districts, as near Oracle and Mammoth, in Pinal co.; in tracts in Pima co., and in portions of Yuma co. In Graham and Cochise cos., and, to a less extent, in Gila co., with occasional outcrops near the adjoining boundary of Maricopa and Yavapai cos., the same trend is prominent. Erosion has exposed portions of the same terrane, thrown into the NE.-SW. trend, in limited areas in Graham and Yavapai cos., and, possibly, in the northeast portion of Yuma co.

There is nothing to be mentioned concerning these rocks which would distinguish them from similar exposures in other parts of the world. A strong expression of chloritic type is noticeable, with abundant quartz seams and bosses. Dioritic intrusions, or thick interbedded layers, are somewhat frequent. Crumplings, contortions and plications are locally numerous.

The quartz-veins in these schistose rocks are apparently not as important as those in later formations; but this remark is "subject to revision." The instances of successful mining in the schist belts are few; but this may be partly due to their structural features. Such cases as are known to the writer indicate for the veins a later origin than that of the first vein-series, but there are also some facts which require further investigation, and these may eventually cause a change of opinion to some extent. Near and south of Oracle, some E.-W. veins

* Professor Wm P. Blake announces the synopsis of a paper to be read before the Cordilleran Section of the Geological Society of America, at the San Francisco meeting in December, 1900. From this I am led to infer that he has some interesting announcement to make regarding a mid-Silurian or post-Silurian uplift. His long term of study of Arizona geology eminently qualifies him to speak understandingly on these topics.

outcrop, which yield a fair amount of gold, but they have never been worked extensively.

The minerals which belong to the schists are, perhaps, more numerous than we now know. Garnets, small and large, have been picked and washed from the sands in the larger river valleys, in regions where these rocks outcrop. In quartz exposures at the northern base of the Santa Catalina range, southwest of Oracle, tourmaline crystals are abundant. It is possible that some of the wolframite of Arizona is similarly placed. Cyanite schist is common in some localities, especially westward. In the southeastern part of Santa Cruz co., near Washington Camp, large dikes of a mineral allied to sahlite appear to follow the NE.-SW. trend. Their relations to the early schists are, however, not evidenced. Asbestos has been reported from the Grand Cañon region. Serpentine occurs in places.

We do not now know the upper and lower limits of the schist group, and cannot safely define the period which these strata represent. The designation at the head of this section is, perhaps, as good a guess as any.

(b.) *The Cambrian (?) Slates*—It is a rough classification which assumes to separate these slates from the schists, on the one hand, and from the partially metamorphosed shales on the other. In so doing, the intent is merely to recognize an apparent natural grouping which may have more or less of chronologic significance. The slates are not unique, and little need be said of their characteristics, except that they are usually much broken and variable to a considerable extent in texture. The exposures are along the edges of the schist outcrops, as defined in the preceding section.

Some of the gold-veins have slaty country-rock. Probably some of the garnets came from this formation, and there may be other important minerals, but the present writer has no knowledge of them in place—unless the marbles belong here, which is doubtful. These occur in many localities, although trade conditions have not yet made possible a successful industry, except in a limited way. East of Tucson (a little north), in the rough country between the Rincon and Santa Catalina ranges, some valuable deposits have been utilized somewhat for monumental purposes. They vary in color, and fair-sized blocks can be quarried.

As to the question of the age of these rocks, the remarks already made under the last head apply here, with simple change of lithologic terms.

(c.) *The Slaty Shales*.—The transition from the slates to what we may be justified in regarding as true Silurian strata, is through an ill-defined series of shaly slates and slaty shales, which have not had much independent study. In these are many of the veins of the Prescott and other regions, and the quartz reefs hereinbefore described are largely associated with this group. They may or may not contain indigenous minerals of economic value, and they may include some sub-Silurian members, but on this last point we know little as yet.

3. *The Silurian Strata.*

The exposures of known Silurian terranes are not as abundant as one might expect from the extensive erosion over the Territory; for the faulting, lava-flows and detrital deposition have together been very effective in obscuring the stratigraphy, and erosion itself has obliterated its due share of the record. Perhaps there are more outcrops than we now recognize as true Silurian, but they are scattered and confusing, making correlation difficult without more study than has been possible thus far to workers in the field. The Grand Cañon section affords good exposures; and there is an interrupted belt, outcropping near Jerome and at other points in the Verde valley, and southward, at intervals, along the course of the Aqua Frio. In southern Arizona, and probably in a portion of northwestern Arizona, there are more or less isolated exposures of these strata, due largely to erosion or to structural features. In the Santa Rita and Whetstone ranges and intervening country, in Pima and Cochise cos., and probably in the Chiricahua and other ranges in Cochise co.,* there are good exposures, although but little work has been done in classifying the strata. The results of boring in Yuma and Maricopa cos are less certain, but they give hints of buried strata of this period in much wider areas.

(a.) *Minerals* —It is not now possible to separate accurately the Silurian strata or to catalogue completely their mineral

* These ranges I have studied, and have seen in them outcrops which appear to me to be Silurian

contents. Some salt-beds in the Grand Cañon region are presumably of this period. It may be that the remote source of the galenas of the veins was of this horizon, and perhaps the deep-seated indications of oil at Gila Bend are chronologically similar. Some of the limestones of this period may have qualifications as hydraulic cements. It is barely possible that the marbles referred to on a preceding page may belong here.

4. *The Carboniferous Strata.*

Passing by the Devonian rocks, concerning which the present writer, at least, cannot presume to say whether they are represented in the section under consideration, we come to the Carboniferous limestones, which are much in evidence over wide areas. They are especially prominent west of the great "Rim"-fault, and particularly in the Huachuca mts and other ranges in southern Arizona. In western Arizona they are less conspicuous, but show many scattered outcrops. The system has great thickness, but has never been worked out in detail. Further south, in Mexico, the rocks of this period are less isolated. The Coal-Measures are represented by a great thickness of strata in Arizona, but the orographic movements to which they have been subjected have materially altered their original texture in very many instances. But few cases of moderate dip are known to the writer, and these are of limited extent. A continuous section of connected exposures cannot be had from bottom to top of the series, but the various patches may usually be correlated by the fossiliferous beds or the coaly layers.

(a.) *Minerals.*—The work heretofore done in this group has been very largely economic. Extensive and possibly valuable coal-deposits on the San Carlos (White Mountain) Indian Reservation have been, by reason of their location, inaccessible to private enterprises. Engineers of the Southern Pacific R. R. Co. have conducted explorations, including some borings in districts east and south of this tract, with results which are not known to the public, but are reasonably supposed to have been unsatisfactory. South of Bowie, in Cochise co., and in the Whetstone mountains farther east, the writer has examined coal-outcrops. There is much divergence in the quality of samples from different localities and still more in comparison with

samples taken from exposures in Sonora. The material near Bowie, in the Chiricahua mountains, is squeezed and crumpled in a fault-line, and has thus become partly altered to graphite, although it can be burned to some extent, with a yellow flame, in a fire previously under way. In the Whetstone mountains considerable beds of bituminous shale show almost a "coal blossom." No development has been made there. The San Carlos coal appears to be of better quality, and might be of economic value. Some of the Sonora coal is reputed to be serviceable, having more the character of anthracite. In the neighborhood of most of the Arizona outcrops there has been more volcanic activity than is compatible with the finding of unaltered bituminous coal.

Limestones suitable for the manufacture of quicklime are more or less abundant in many localities. Beds adapted for use as flux in smelting are to be obtained in many districts, and many of the best ores of copper and lead are closely associated with such terranes. Some building-stones may be included in the series, but, as yet, these have not been employed to any extent beyond the requirements of the railroads for abutments and foundations and for reservoir-dams.

Some beds of hematite, associated with copper carbonates and oxides in interbedded deposits, occur at Planet, on Bill Williams Fork, near the boundary between Yuma and Mohave counties.

In the Squaw Peak district, east of Mayer, occurs an interesting series of variegated dolomites, locally termed "lithographic stone." Some of these have been employed successfully in practical lithographic tests on a small scale. The markings are very curious and the tints are often attractive. They will probably be utilized as decorative stones in architectural work when they have been properly introduced to the trade.*

5. *The Strata of the Jura-Trias.*

The main field of post-Carboniferous outcrops lies east of the "Rim"-fault, or great central axis of disturbance. Exposures west of this line are very few and insignificant. Good sections

* Prof. J. F. Blandy, of Prescott, has contributed a valuable article on this "lithographic stone" to the *N. Y. Eng. and Min. Journal*.

occur in the Verde valley and its side cañons, and there are excellent examples over much of northwestern Arizona.

The Jura-Trias strata are especially marked by the presence of the brick-red sandstones. The dip is usually moderate, and the greater portion of the existing remnants of this series is protected by cappings of more durable calcareous beds of later origin. Apparently this complex group thins out before reaching the southern portion of the Territory, although there are occasional exposures of red sandstones, which appear to be much more recent, in the cañon of the San Pedro and other tributaries of the Gila

At Flagstaff, and to some extent elsewhere, very serviceable building-stones are quarried, varying in tint from pink to drab, according to the relative proportion of ferric oxide in the sand-rock. Attempts were made to utilize similar materials near Rock Butte Station, in Yavapai co., but being directly on a fault-course, the strata were too much broken to yield suitable prisms. Much of the rock was, however, successfully employed in railroad work, requiring only rough masses of irregular dimensions.

The limestones are not much used, except, possibly, for burning to lime in one or two localities. Some gypsum has been mined in Pima co., east of Tucson, and other deposits are known in the northeast. There may be remnants of the same strata in limited areas in northwestern Arizona, since gypsum beds appear in Nevada, not far west of the Colorado river.

6. *The Cretaceous Strata.*

Without more study, it is about as difficult to define the upper limits of the Cretaceous as to separate the basal strata from those of the preceding period. Very instructive sections occur along the San Pedro river, in the upper Gila valley, and elsewhere. From these it appears that much of the Cretaceous area of deposition was not submerged during later epochs. Apart from the possible use of limestone for quicklime and for building, there is not much material of economic importance in this series of strata.

7. *Tertiary and Later Strata.*

The Tertiary volcanics have obscured much of the sedimen-

tary terranes, and the study of the later rocks has been but desultory. No attempt to classify them will be made here, but some very general remarks may not be amiss. Undoubtedly there are remnants of strata more recent than the Cretaceous, and probably large areas are exposed at the surface over the southwest part of the Territory. There is also some reason to infer that these extended more or less connectedly up into the Colorado river valley in western Arizona, if not northward as far as has been supposed by some oil-seekers in Mohave co. Detrital deposits of enormous thickness occupy large areas, and with these are somewhat confusedly intermingled very considerable patches of fragmentary material of local origin. In some cases these last are more or less entangled with the volcanic outflows, particularly those of the Crater-period.

(a.) *Minerals*—The mineral contents of the accumulations of post-Cretaceous and recent date have not been exploited extensively. In many localities, auriferous gravels are sufficiently abundant and valuable to justify the application of modern methods on the large scale, but these are not always in districts well supplied with water. The Greaterville tract, in Pima co.; the Weaver, Oro Fino, Aqua Frio and other districts, in Yavapai co., and the Colorado river bed, at least from the lower portion of the Grand Cañon, near Scanlon's ferry, practically down to the Pacific Ocean, are notable examples of pay-gravels. The first and second named are deficient in water, and have been to some extent depleted by the crude methods of hand-picking and "dry-washing." The other cases here cited are not lacking in water; but, as a rule, liability to floods limits the range of appliances adapted to their successful working. But in most instances the want of ample capital has been the chief source of failure to reap adequate reward in the past. French capital has been liberally expended in dams, heavy pipe-lines, pumping and current-acting machinery, at Temple Bar, a few miles above Bonelli's ferry, between the Grand and Black cañons of the Colorado. The results are not publicly known, but the company has not been actively working for some months past. A Denver firm has recently launched the Alliance Gold Dredging Company to work placer-deposits on the lower reach of the Colorado, between Needles (Cal.) and Yuma. There are many similar deposits in various parts of the Territory, and a profit-

able industry may yet grow out of this class of mineral resources.

The possibility of developing a limited oil-field in western Arizona is within reason, but that is not by any means an alluring hope. Petroleum occurs in California in terranes ranging from Eocene to Quaternary. Perhaps Arizona has rocks enough of these epochs, so situated as to afford restricted oil-bearing tracts, but this is uncertain. Natural gas exudes at places in the lower Colorado river valley, where strata of these periods are most likely to occur; but no developments have yet been made which settle the doubt whether the gas may not be a product of still more recent origin.

The so-called "Mexican onyx," in reality a calcareous tufa in some of its exposures, and, possibly, a marble of much earlier date in other instances, will one day form a very important part of Arizona's mineral output. At Mayer, Yavapai co., are the Big Bug quarries, which present the material in fair position for economic handling and in great variety of tints and markings*. Very satisfactory exposures near Greaterville, in the Santa Rita mountains, Pima co., and elsewhere in the same general region, have attracted some attention.

The volcanic conglomerate or breccia, which forms the floor of the Mayer deposit, is not as clearly evident near Greaterville, but the general conditions make it probable that the origin was similar. In the latter case, the mass was discovered in a tunnel cut through coarse fluvial gravel (or, possibly, a remnant of volcanic *débris*), and the tufa appears to be formed in a line of contact with porphyry, or in an old fracture in the lava. There are many good exposures of the volcanic fragmental rocks in the cañons of the Gila region, and it is possible that more of the tufaceous "onyx" will be discovered.

Interesting hot springs occur in situations indicating close relation to comparatively recent volcanic action. The best-known examples are the medicinal springs in the Bradshaw mountains, north of the line between Yavapai and Maricopa cos.; the Agua Caliente, on the Gila, in Yuma co., and the Hooker hot

* Prof Blandy described the Big Bug (Mayer) quarry in the *Eng and Min Journal*, March 26, 1892, and further reference was made to it in *Mineral Industry*, vol 1, 1892, p 359.

springs, northwest of Wilcox, at the north edge of Cochise co. Sulphur-springs are somewhat abundant, being apparently disposed with reference to volcanic influences, but not according to any system as yet recognized.

There are other minerals which may at some time support special industries. Under the general term kaolin, we may here include a considerable variety of disintegrated feldspathic and other deposits, which have been reported from many localities. In the Longfellow mine, near Clifton, Graham co., this mineral forms the wall of the vein, and, mixed with two parts of sand, is used as a refractory material in furnace-work *. A similar deposit of great width accompanies the vein in parts of the Jersey Lily mine, Yavapai co., and the same feature, with uncertain relations, is strongly evident in several of the claims of the Consolidated group, lying parallel with the Jersey Lily. In this district (where the writer is at work) some interesting observations have been made in connection with the kaolinization, but safe conclusions cannot be drawn from them without more extensive development. The same effect has been produced largely in portions of the Elkhart and other mines in Mohave co., but the conditions appear to have been different there. While I was Director of the School of Mines, at Tucson, some samples of very excellent white kaolin were sent to me from different parts of the Territory. With the foregoing local deposits of porcelain-clays are to be mentioned abundant accumulations of clays suitable for brick-making, adobe materials and the like. A good quality of white (buff) brick is now manufactured at Winslow, Navajo co., and excellent red brick is produced at Phoenix, Tucson, Yuma, Prescott, Flagstaff, Kingman and other towns.

The volcanic layers furnish material suitable for railroad use as track-ballast, and for road-metal. Silicified wood, from the "petrified forest" of Navajo co., has become an article of commerce to some extent.

Alum has been reported.† Some very good specimens of artificially crystallized soluble salts have, at times, been sent to mineralogists as samples of available commercial minerals; and other efforts to deceive the unwary have been exposed.

* *Mineral Industry*, vol ii, 1893, p 204

† *Mineral Industry*, vol ii., p 5

SECRETARY'S NOTE.

By reason of unavoidable delays in the preparation, printing and final correction of the following papers, they have been set over to Vol. XXXI.

Biographical Notice of Thomas Egleston, Ph.D., LL D., by George F. Kunz, New York City.

Remarks on Mine-Surveying Instruments, with Special Reference to Mr Dunbar D. Scott's Paper on their Evolution, and its Discussion, by H. D. Hoskold, Inspector General of Mines of the Argentine Republic, Buenos Aires, S. A.

Notes on Mine-Surveying Instruments, with Special Reference to Mr. Dunbar D. Scott's Paper on their Evolution, and its Discussion, by Benjamin Smith Lyman, Philadelphia, Pa

With regard to the two papers last-named, it may be added, that they will be contained, with others upon the same subject, in a special volume upon the Evolution of Mine-Surveying Instruments, to be issued at an early date, and before the publication of Vol. XXXI.—R W. R

DISCUSSIONS.

The Evolution of Mine-Surveying Instruments.

Continued Discussion of the Paper of Dunbar D. Scott, presented at the Buffalo Meeting, October, 1898 (See *Trans*, xxviii, 679)

SECRETARY'S NOTE.

This continued discussion will be found at p. 783 of this volume, and in the paper of Mr. Davis, beginning on p. 803. Further papers on the subject by Mr. H. D. Hoskold, Inspector General of the Argentine Republic, Buenos Aires, Mr. B. S. Lyman, Philadelphia, Pa., Mr. J. H. Harden, Phoenixville, Pa., and Mr. Scott, the author of the original paper, will be published in Vol XXXI.

Coal-Outcrops.

Discussion of the Paper of Charles Catlett, Staunton, Va. (See p. 559)

BEVERLEY S. RANDOLPH, Frostburg, Md. (communication to the Secretary) It has always appeared to me that each coal-seam has its peculiar character or habit, due to the conditions of its formation, by virtue of which it is either persistent or variable in its section over extended areas. One seam will hold its thickness, chemical character, number and position of partings, beds of slate, etc., over a large area, while another will be found to vary in some of these characteristics every few feet.

As the position of the outcrop is an accident of the topography, depending on folding and erosion which have taken place since the bed was formed, no one opening in the outcrop, or, in fact, anywhere else, can supply reliable evidence as to the general character of the seam.

To determine the character of an untried seam, a number of sections are necessary from widely separated points, in order to show such variations as may exist. Should material variations be developed, more numerous sections are necessary, in

proportion to the extent and character of these variations. These can usually be most cheaply obtained by excavations in the outcrop.

While such outcrop-sections are valuable in determining the habit of the seam, I do not consider them safe data on which to base important deductions, since they are always more or less affected by weathering and the percolation of surface-waters, and it would scarcely seem possible to determine what was originally in the section by what remains after such action. A reasonable amount of development under cover would appear to be necessary in order to determine what changes obtain in the outcrop of each seam.

As illustrating this, I have now in mind a property in West Virginia, consisting of several thousand acres, on which some twenty-odd openings had been made in the outcrop. These were driven in until the roof showed solid and in place. All of them exposed (within a few inches) the same thickness of coal, and about 30 in. from the floor a small slate bed was uniformly present, being in one place about 2 in. thick, but usually less than half an inch.

As these openings were well distributed over the property, this was a most encouraging showing. But when this seam was developed under cover, the small bed of slate increased to about 18 in. in thickness, persistent over the whole property, while numerous smaller and less persistent beds, which did not show in the outcrop-openings, were found in other parts of the seam, materially affecting its value.

It appeared as though the action of the surface-water had leached out these slate-beds at the outcrop, leaving the coal clean.

MR. CATLETT Mr Randolph certainly describes a very interesting case of *uniform irregularity* in a coal-seam, the outcrop being so uniform in certain respects, and the seam, as developed, being so uniform in certain other respects. It well illustrates the irregularities which *may* occur in coal seams, and which may almost be said to be characteristic of their mode of formation.

I would be interested to know, however, whether the changes to which he refers took place within 50 or 75 feet of the out-

crop If not, it is doubtful whether they should be attributed in any way to the action of surface-agencies, and not rather to the original formation of the coal in a basin

MR RANDOLPH. The property in question lies at the end of the basin, where the measures are rising to the surface along the line of the axis. I saw two openings which had been driven in far enough to develop the full thickness of the slate mentioned. In each case the thickness gradually increased, attaining the normal dimension of about 18 inches some 50 to 75 feet from the point where the tunnelling began.

One of these openings was situated near the axis and the other about a mile from it. The property has been quite extensively worked since, and while I have not had an opportunity of observing it personally, the statements of several persons who are familiar with the workings agree in indicating that the slate bed is uniformly present, as stated.

C SCHOLZ, Mammoth, W. Va. (communication to the Secretary) Mr. Catlett's paper calls attention to facts not as well known to the geologist as they deserve to be. In view of the constantly increasing value of coal-property, it is obvious that the engineer entrusted with the determination of the value of such lands should be in possession of all information bearing on this subject. While, in well-defined coal-measures, "mine-salting" cannot be practiced, as in metal-mining, yet there are ways in which the prospector can make the result of his work so appear as to favor the interest he represents.

For instance, after careful observation I have concluded that where a tract of land is badly cut up by deep branches and ravines, the thinnest and poorest coal (constituting the lowest part of the bed) will usually be found under the long and narrow points, and the best and highest coal under the more compact ground. By keeping this fact in mind, a fair idea can be formed as to the general condition of the seam from its outside appearance. The coal under the points is also usually discolored and of a dry character, making a very dead and inferior fuel.

Since the coal was formed long before the valleys, no explanation of this difference can be sought in original conditions;

and we must ascribe it largely to two causes · first, that portions of a soft coal-seam having the greatest thickness gave better opportunities to erosion (as is shown by the fact that the wider benches follow the outcrops of the thicker seams), so that we must believe that, in such cases, a portion of the most valuable coal has been swept away, and secondly, that the pressure of other strata has had more or less to do with the compression and displacement of the coal in smaller areas and narrow strips—when the coal, perhaps, had not reached its present degree of hardness. The result is shown in Fig 3 of Mr Catlett's paper.

It follows that for the owner of the land, who wishes to show it off to the best advantage, the most desirable location for an opening is usually near the head of a drain or valley, where the strata appear to be in position; the crop-dip will not affect the thickness of the seam as much there as it would on the point of a mountain, for the reasons given above.

This crop-dip affects to some extent the thickness of the coal on the outcrop line, and it is necessary to study the conditions of every seam, before definite conclusions can be formed as to how the seam will open up. For instance, where a rock-roof is found, or there is but little slate or fire-clay between the coal and the sandstone above, but a considerable thickness of slaty strata below the coal, we may expect to find the coal to increase as it is driven upon, since the more plastic slates have been swelled by the action of the atmosphere, causing, together with the pressure from beneath, a compression of the coal on the outcrop; but where the floor and roof are of about the same material and thickness, it is not likely that the coal has been thus affected. By keeping this condition in mind, pretty close estimates can be made by "facing-up the coal," without driving under rock-roof for any great distance. I do not know of any certain and general rules, but believe that practical experience is in this matter the best instructor.

Where lands of higher valuation are concerned, it is well to test with the diamond-drill the persistency of coal-seams established by crop-openings. This method leaves no room for doubt. Moreover, the drill-cores, besides giving information as to the character of the deposits above the coal, may be useful in establishing the most suitable system of mining, and in fur-

nishing material for analysis, which is of special importance in the case of coking-coals.

In drilling for a seam, which was found about 150 ft. below the water-level, the drill penetrated, at only about 10 ft. below the surface, the Cedar Grove seam, well-known in the Kanawha valley, which usually has a thickness of 36 to 39 in., but showed in this case 4 ft 8 in. Additional drilling proved that a considerable territory was underlain by 5 ft. of coal, where only 3 ft was expected—the last opening above water-level, only half a mile away, having shown a section of 36 in.

The mistakes of prospectors have their humorous side. I recall an occasion when, in one of the back counties of West Virginia, I came to a mine from which the farmers of the vicinity obtained their winter coal, and found the mouth securely nailed up with boards. That night a man came to my camp and, after some cautious inquiries, produced from careful wrappings a ball of glittering "sulphur." He was the owner of the mine we had passed during the day, and only with great difficulty could I persuade him that his "find" of pyrites was not valuable.

During the same trip, I stayed over night at a farm-house on a ridge about 800 ft above the Little Kanawha river and found the owner engaged in laboriously hauling his supply of coal for the winter from an opening near the foot of the mountain. On the following morning, I found that the large bench behind his house was on the horizon of the Upper Freeport coal; and an opening showed this seam to crop out more than 4 ft thick, only a few feet from his coal-shed

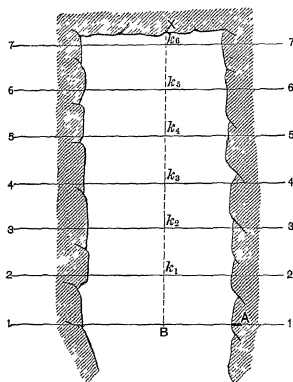
A Method for Obtaining the Volume of Small Drifts and Working-Places, Where it is Impossible to Use a Transit.

Discussion of the Paper of C S Herzig, Virginia, Minn (See p 778)

FRED. T GREENE, Rossland, B C. (communication to the Secretary) At the beginning of his paper, Mr. Herzig refers to an article of mine in the *Engineering and Mining Journal* of January 27, 1900. I would like to add that the method de-

scribed in that article was afterwards used to find the amount of ground "in place," broken down by each successive blast, with the object of getting data upon which a fair scale of contract-prices could be based. To attain this end, the method described in the article was used with very slight modifications. The work had to be done so as not to stop the machine-drills or interfere in any way with the men employed in the stope. Each machine had to be visited as soon after blasting as the mass broken down could be cleared away, and as there were

Fig 1

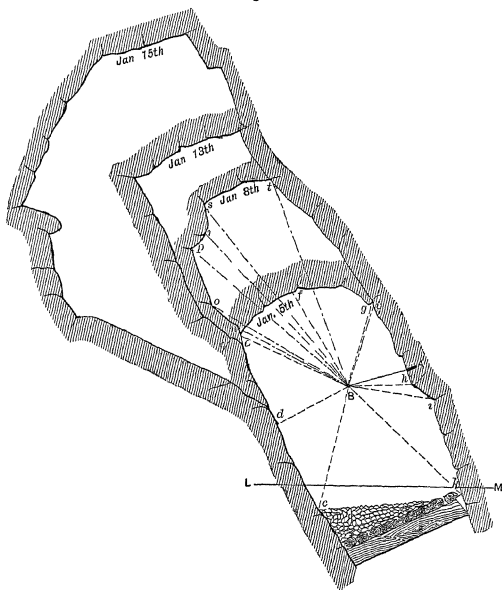


Plan of the Excavation to be measured

nine workings (one with three machines, three with two, and five with one), the amount of time available for measurements in each place was necessarily small. Fig. 1 is a plan, and Fig. 2 a vertical cross-section, of one of the working-places where one machine was at work, breaking the ground down from the back of the stope, which was floored as shown in Fig. 2. A wooden plug pierced longitudinally with a hole $\frac{3}{8}$ in in diameter was put in the hanging-wall at a convenient point, A, and a rod AB, of $\frac{3}{8}$ -in. round steel, with one end bent to an eye, was inserted in this plug. From B, a string BX (Fig. 1), knotted at every two feet, was stretched horizontally, parallel to the

hanging-wall. At B, and at each knot (k_1, k_2, k_3 , etc.), cross-sections, at right-angles to BX, were taken in vertical planes at 1-1, 2-2, etc. (Fig 2), by stretching the tape from B, or from the appropriate knot, to points of change of contour, such as c, d, e, f, g, h, i and k ; and determining the angle from the horizontal by means of a very light pendulum-clinometer, clamped

Fig. 2



Vertical Cross-Section through AB (Fig 1)

to the tape. The tape-distance and vertical angle to each point, when plotted, gave a very accurate cross-section at each knot. A reference line, L M, Fig. 2, having been chosen, the areas of the several cross-sections were ascertained with a planimeter. These gave the ends of a series of prismoids, from which the cubic volumes could be readily figured. In the

cross-section shown in Fig. 2, the contours were first taken on January 5th, to get an outline, *c, d, e, f, g, h, i, k*, from which to start. The next contour, *n, o, p, r, s, t, v*, was taken January 8th, and the increase in area of each cross-section furnished the basis for calculating the volume broken down.

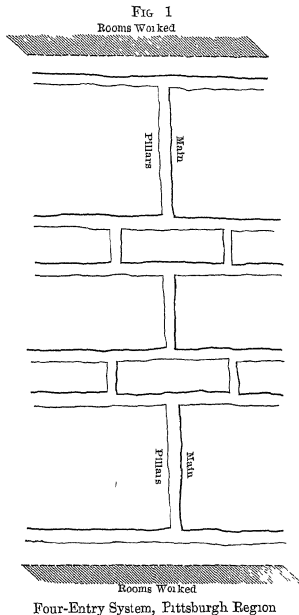
An accurate record was kept of the time occupied in drilling, blasting and delays, as well as an account of all supplies, powder, etc., consumed at each working-place. From this information there was calculated a scale of prices, for each character of working-place, covering every condition likely to be encountered at that place, and to affect the fair operation of the contract-system. In the stope shown in my article cited by Mr. Herzig, we had a very good check on the accuracy of the method. That particular stope, according to the office-records, produced 11,134 tons; and our cross-sectioning showed 10,867 tons, an error of 2.15 per cent. In this case, however, the accuracy of the method depended more on the care taken in determining the specific gravity of the ore than on the survey itself. If the ore had been homogeneous throughout, there would have been little difficulty under this head, but a great many experiments had to be conducted, with pieces of ore as large as possible, in order to obtain the average number of cub. ft per ton of ore. The number obtained in this case was 8.85, corresponding to a specific gravity of 4.05, while from the analysis of the ore the specific gravity obtained was 3.97, indicating that the factor should be 9.04 cub. ft per ton. The mean of these two factors, 8.96, was used in obtaining the above result, showing only about 2 per cent of error.

A New Method for Working Deep Coal-Beds.

Discussion of the Paper of H. M. Chance, Philadelphia, Pa. (See p. 285.)

W. S. GRESLEY, Erie, Pa. (communication to the Secretary): A six-entry method of opening coal-mines is, or was a short time ago, practiced in the Connellsville coal-region; but Dr. Chance's method has a novel aspect, for while in the Connellsville region the main pillars are formed outside of two pairs

of main headings, with a single entry driven along the outer sides of the main pillars and near to the rooms (see Fig. 1), Dr. Chance's plan provides the main pillars beyond or outside the six entries, which would seem to be the better plan. In the Pittsburgh region the air-courses flanking the main haulage-way and travelling-way are frequently driven of the width of



an ordinary room or breast, as suggested by Dr. Chance, in this case practically making a four-entry system for the main roads.

It is suggested, for the sake of economy, that the entries or gangways should be driven as narrow as possible. In some of the deepest coal-mines in England, the weight or pressure

on narrow drivings in coal is so great that they cannot be maintained except at great expense. This is especially the case where the coal-veins worked are thin, and a considerable quantity of material must be removed from the roof or floor to give sufficient headroom on the main entries. When this condition prevails, or when the coal worked contains a considerable quantity of slate or rock, it is found that the openings can be driven and maintained more cheaply by giving to the headings a width considerably in excess of the actual requirements, and filling the space on one or both sides of the entry with closely packed gob, thus providing for such slight subsidence or squeeze as may occur, so that after a short time they become settled and require but trifling repairs. Moreover, by this method stowage-room is secured for waste. In Nova Scotia, I believe it has been found better to take out several yards of coal on the dip-side of entries driven at great depths (1900 feet?) and to stow the excavation with débris, in order to maintain good roadways in the seams. I am therefore of the opinion that while, under ordinary conditions, as depth increases, the narrower the gangways and headings are made, the better, yet it may be, in some instances, a question of conditions as to whether gangways and headings in deep mines should be driven wide or narrow, in order to insure the least cost of maintenance. A case occurred some years ago in a deep colliery in Scotland where, in order to maintain the entries or levels in a pitching seam, several yards of floor had to be excavated and replaced by rubbish, stowed, in fact, all along the gangway.

In foreign countries, where many of the coal-mines are getting very deep, the room- and pillar-systems are gradually, if not quickly, being abandoned in favor of the long-wall method, this being chiefly necessary, I believe, on account of the impracticability of keeping open the headings driven in the coal.

C. R. CLAGHORN, Vintondale, Pa (communication to the Secretary). I would like to inquire why the method proposed in Dr. Chance's interesting paper is limited by his title to "deep" coal-beds.

It seems to me equally applicable to almost any bed where pillar-and-stall working is admissible. I may add that I re-

cently visited some pits in the north of England where a somewhat similar system of laying out work for ventilating purposes is in use. As regards very deep seams, I should think that the thickness and character of coal and nature of roof would have a material bearing upon the system to be employed. In the midland counties of England, pillar-and-stall work is not generally considered admissible under very heavy cover, since it would be impossible in such cases to maintain even narrow headings without constant repair, or to drive even narrow stalls with the expectation of their standing sufficiently long to permit the extraction of the pillar. Long-wall is therefore generally considered preferable to pillar-and-stall in these very deep seams, though post-and-stall is sometimes used in thick coals.

Any system which will enlarge the territory tributary to a colliery by facilitating ventilation, haulage, etc., is worthy of consideration; and I should say that Dr Chance's method would be as applicable to coal-seams at light and moderate depths as to deep seams, and that the limitation in title is, therefore, misleading, especially as, in very deep seams, pillar-and-stall work might not be admissible at all.

DR. CHANCE (communication to the Secretary) I agree entirely with Messrs Gresley and Claghorn regarding the advantages of long-wall for very deep workings in small or dirty beds of coal; but the system described can be used *in opening* coal for long-wall work as well as for any other method of working. Mr. Claghorn rightly criticises the title of the paper as misleading, since the method is as well adapted to comparatively shallow workings as to deep workings. The writer was unconsciously led into this error, because the system was originally devised by him to meet the requirements of deep and gaseous workings. But it may also be used profitably in shallow workings free from gas.

Regarding the British instance, quoted by Mr. Gresley, where entries are driven very wide and the sides are filled with rock taken from roof or floor, the writer may observe that, at a large anthracite property in Pennsylvania with which he is professionally connected, a thin bed of coal is now successfully worked in this way.

The Clealum Iron-Ores, Washington.

Discussion of the Paper of George Otis Smith and Bailey Willis, Washington,
D C (See p. 356)

W. M. COURTIS, Detroit, Mich (communication to the Secretary) Having made a rapid examination of the deposits described in this paper, I am not inclined to generalize confidently concerning its geological relations. But, since an analysis furnished by me has been included in the paper, it may be of further use to give the results of other samples and analyses.

I give, therefore, a table of analyses by different parties, showing the average from surface-specimens.

Analyses of Clealum Ores

		Denny Mine, Rich Ore Body, Courtis & Smith	Clealum, Average in Pit-bottom Monarch Mine, Courtis & Smith	Denny Mine, Average of 5 Samples, Courtis & Smith	Clealum, Average of 17 Samples	Clealum, Average of 900 lbs, Dr C F Chandler
Sesquioxide of iron	Fe ₂ O ₃	55 370	35 324			
Protoxide of iron	FeO	29 160	21 887			
Alumina	Al ₂ O ₃	4 500	20 376			0 600
Sesquioxide of chromium	Cr ₂ O ₃		1 929			
Manganese oxide	MnO	1 362				0 110
Nickel and cobalt	Ni, Co					
Titanic acid	TiO ₂				traces	
Lime	CaO	7 560	3 360			
Magnesia	MgO	0 265	0 720			
Silica	SiO ₂	2 350	8 950			10 280
Silver	Ag	traces	traces			
Gold	Au					
Phosphoric acid	P ₂ O ₅	0 001	0 142		0 102	0 032
Sulphur	S	0 119	0 130			trace
Excess or undetermined		0 687				
Loss on ignition			5,700			5 30
Metallic iron	Fe	61 425	41,737	64 879	42,357	55 080
Phosphorus	P	0 0004	0 062	traces.	0.044	0.0139

Analyses of Clealum Ores—Continued.

		Clealum, Average of 25 Samples, Moss Bay	Clealum, Average of 6 Samples, Dr Riley	Clealum, Lowest Work, on the Monarch, Prof Dodge	Clealum, Average of 11 Samples, Mr Bacon
Sesquioxide of iron	Fe_2O_3				
Protoxide of iron	FeO				
Alumina	Al_2O_3		7 51	0 84	
Sesquioxide of chromium	Cr_2O_3		3 352	1 33	
Manganese oxide	MnO		1 050	traces	0 431
Nickel and cobalt	Ni, Co		0 93		
Titanic acid	TiO_2				traces
Lime.	CaO		0 740		
Magnesia	MgO		2 720		
Silica	SiO_2		7 410	6 07	9 45
Silver	Ag				
Gold	Au				
Phosphoric acid	P_2O_5	0 042	0 080		0 07
Sulphur.	S	0 035	0 041	none	0 170
Excess on undetermined					
Loss on ignition					
Metallic iron	Fe	50 25	51 11	60 95	51 05
Phosphorus	P	0 018	0 036	0 01	0 03

To give an idea of the range of the Clealum ores, I add from the data in my possession the results obtained by different parties. These do not include samples not really iron-ore

Metallic Iron.

	Lowest Per cent	Highest Per cent
Dr Riley,	47.10	55.35
Moss Bay,	43.20	57.00
Mr Bacon,	31.90	58.85
Courtis & Smith,	27.95	62.40

In taking my samples, I did not include any very rich selected pieces. I have some that would equal the highest figures above given; but I tried to get at each point an average, so far as appearance could serve as a guide.

A Peculiar Siliceous Efflorescence upon Pig-Iron.

Discussion of the Paper of B F Fackenthal, Jr., Riegelsville, Pa (See p 524)

PROF HENRY M HOWE, New York It is extremely probable that this efflorescence of silica is due to the liquation either of silicon or of a silicide, and the subsequent oxidation of the silicon to silica As Mr. Fackenthal says, it is very hard to see why silicon should liquate from an iron containing so little silicon, and it seems more probable that some silicide of some volatile element has liquated, and has dissociated on reaching the air, and that the volatile element has volatilized, leaving the silicon to oxidize to silica

The volatile elements present which might thus liquate in combination with the silicon are sulphur, zinc, and lead

It is hard to see why sulphide of silicon should have liquated from an iron containing so little of either sulphur or silicon.

At first, one naturally thinks that either the zinc or the lead present in this furnace might have liquated as silicide. It is true that they are both volatile at the temperature within the furnace, but then the vapor-tension* of each of them within

* The matter of vapor-tension may need a word of explanation for some of our members If the valves of a steam-boiler be completely closed, so that none of the steam can escape, the water will continue evaporating until the steam reaches a certain definite fixed pressure, or, more accurately, until the quantity of steam in each cubic foot of space above the water reaches a definite amount corresponding to equilibrium When this amount is reached, it completely restrains further evaporation (or, more strictly, from this point on, the evaporation is exactly equalled by the simultaneous condensation) This amount, known as the "vapor-tension," varies with the temperature, but for given temperatures is fixed

My idea is that in the blast-furnace the lead, for instance, would in like manner exist, in part, in the form of vapor of metallic lead, and in part be alloyed with the molten cast-iron, the quantity of vapor of lead in each cubic foot of space above the molten cast-iron within the furnace being great enough to arrest the further volatilization of lead, and so causing part of the lead to remain in the liquid state in cast-iron, just as the presence of a sufficient amount of steam in each cubic foot of space above the water in the steam boiler prevents the further evaporation of the water But when the pig-iron runs out of the blast-furnace, it is now exposed not to the atmosphere of the furnace, assumed to be charged with vapor of lead or zinc, but to atmospheric air And, just as the water in the steam-boiler will keep on evaporating indefinitely, if, by opening a valve, we allow the steam to escape, so the lead contained in molten cast-iron will, according to my explanation, immediately evaporate so soon as the atmosphere immediately above it ceases to be charged with vapor of lead

the furnace may easily have been high enough to prevent them from volatilizing completely there, so that the pig-iron, as it flowed from the furnace, might well contain both zinc and lead. It is also easy to understand that, once the pig-iron reached the open air, and the vapor-tension of lead and zinc which existed within the furnace was thereby removed, the lead or zinc should liquefy as silicide, and immediately volatilize.

The difficulty in the way of this explanation is that the zinc or lead, on volatilizing, ought immediately to have oxidized, and the oxide ought to have been noticed, if not on the pig-iron itself, then on the workmen's tools, the walls, etc. The fact that such a phenomena seems to have escaped notice certainly opposes my explanation.

The Colorimetric Assay of Copper.

Discussion of the Paper of J D Audley Smith, Clifton, Arizona
(See p 851)

GEORGE L. HEATH, South Lake Linden, Mich. (communication to the Secretary). In presenting some notes on the "Heine's Blue Test" Mr. Smith expresses a preference for fresh standards and a cheaper bottle; but this is rather a reversion to the old method, since I devised in 1897 the newer method of preparation and preservation of permanent standards, which were not used with any success in the original method.

Many busy western assayers no doubt value a method for preparing a permanent set of standards in air-tight glass-stoppered bottles, whose use brings the method as near perfection as one could desire as regards rapidity of color-reading and avoidance of unnecessary work.

Mr. Smith notes that his color-readings were compared with an electrolytic assay of another ore-sample, and that my electrolytic assays were made on the "blue test" solution from colorimetric assay.

He omits, however, reference to the fact, showing the advantage of my procedure, that the next column in table of

results in the original paper* showed the copper as (determined by battery-assay) remaining in the precipitate of iron oxide and silica from the colorimetric assay.

The sum of the electrolytic tests of the blue solution and the residues gives the true copper-contents of the original ore without introducing the element of error of sampling, as Mr Smith has done by testing two samples instead of one in each experiment

The experiments, in my paper referred to, indicated more than this, as they showed by the method of tabulation, etc., described, how nearly one may read the color of a known amount of copper in a solution, and how near that ammoniacal solution comes to containing the total copper originally present in the test-sample.

As in the color-method for carbon in steel and the cyanide-titration of copper, there must be for close work a careful adherence to uniform conditions and agreement of tint or shade between standards and assays.

A set of unchangeable standards containing a definite quantity of ammonia ought to permit closer work, since the tint varies with excess of ammonia from purple to clear blue and even greenish blue.

In further discussion of the question—If standards may be made so that they are good for months afterwards, is there any object in wasting time to make up fresh ones each day? I would say that it is true that bottles made from selected tubing with tightly-ground stoppers may be a little expensive for a private laboratory; but the price (about \$1 each) ought not to be objectionable to a company when much is gained by their use.

A set of 24 uniform bottles, in which the 200 c.c. marks do not vary more than $\frac{1}{8}$ inch from each other, will allow 12 bottles for standards and 12 extras, and should last for many years.

If standards of permanent nature are desired, both a strongly ammoniacal copper sulphate solution and containing-bottles with tight glass stoppers are indispensable, according to our experience. If a chemist prefers the old make-shift, involving fresh standards every day, there is nothing more that I can add to this discussion

* *Journal of Amer. Chem. Society*, vol. xix., January, 1897, p. 24 et seq.

MR. SMITH (communication to the Secretary). In commenting upon my modification of the color-test, Mr Heath considers it a reversion to the old method, and objects to the waste of time in making a fresh standard. The old method requires a fresh standard to each assay-solution, on the other hand, in the method described by me, one standard will do for a batch of samples—as large as may arise in the routine-work of the chemist. At the same time it only takes about one minute to fill the standard tube with the requisite amount of water, acid and ammonia, and the titration does not take any longer than the comparing of solutions with permanent standards. Having used both methods for several years, I do not hesitate to say that I find my method as rapid as Mr. Heath's, and for reasons stated in my paper prefer to use it. Mr. Heath was the first chemist to make permanent standards possible, and his bottle is as perfect as can be made. If, however, fresh standards can be run with one or several assays at once, and as rapidly as with standard colors, then there is no reason why a chemist should go to the trouble of preparing the latter. There is no reason why the same uniform conditions cannot be observed in making the fresh standard as well as by any other method, so that Mr. Heath's remarks on this point are unnecessary.

With reference to my electrolytic assays being made on a second weighing of ore, it seems to me preferable to do this in checking assays, as the errors in weighing will then be reduced. Averages are always more reliable than single assays. My experience with the bottles made from selected tubing has been rather unfortunate, they being so easily broken by the laboratory attendant. If a cheaper bottle can be used, and at the same time the results are accurate and obtained rapidly, it is unfair to class the device as a make-shift. Simple apparatus is always effective if suited to the work required.

The Assay of Copper-Materials for Gold and Silver.

Discussion of the Paper of L. D. Godshall, Spokane, Washington (See p 529)

A. R. LEDOUX, New York City. The so-called "combination method" is generally used in assaying bar copper for silver. It has been modified from time to time. Briefly outlined

as now practiced, it is as follows One A. T. of the borings is dissolved in dilute nitric acid When solution is complete the liquid is boiled and then filtered to remove gold. The filtrate is treated with sufficient salt solution to precipitate all the silver, but avoiding any unnecessary excess. The liquid is allowed to stand over night and next morning the silver chloride is collected on a fresh filter, which, together with the paper containing the gold and insoluble matter, is scorified and cupelled Formerly many assayers added sulphuric acid to the nitric acid solution of the copper and silver and then acetate of lead, thus producing a heavy precipitate of sulphate of lead which was supposed to entangle the silver chloride and prevent it from passing through the filter. As a matter of fact the use of sulphuric acid and lead salts is entirely unnecessary. Very few assayers now make use of them If it is not possible to let the silver chloride settle over night, accurate results may be obtained by stirring the liquid vigorously with some form of mechanical stirrer for half an hour. The silver chloride may then be easily filtered without fear of any of it escaping through the filter. The same result may be attained by blowing air through the liquid. It is quite possible to make an accurate assay by this method in three hours. In some cases, noticeably those in which the copper is very free from impurities and the gold contents small, the correct gold assay may be obtained by parting the bead obtained by this process. In many cases, however, the gold assay obtained by the above process is too low, even though the gold be removed from the liquid by filtration before adding the salt solution It would appear that sometimes the gold is present in the copper in some combination which is soluble in nitric acid or strong nitrate of copper solution. However, it may be, and frequently is, necessary to resort to the "all-fire method" to obtain correct results. This method consists in weighing out a number of 1/10 A. T. portions—usually ten—and scorifying them with lead until most of the copper is removed—then cupelling the lead-buttons either separately or uniting them five and five, rescorifying, and then cupelling. This method is expensive and laborious, involving many scorifications and the use of much test-lead. The first scorification must be conducted at a high temperature, and the operations consume a great deal of time and muffle-room.

But the gold obtained is *usually* appreciably more than can be extracted by the combination-method—though it does not seem to bear any fixed ratio to it even in the same class of copper. In general, in 96–98 per cent copper, containing from 1 to 5 oz. of gold per ton, the “all-fire” results will be from 0.1 to 0.3 oz. higher than can be obtained by the combination-method. Any method that would give correct gold and silver results on *all* classes of bar-copper at one operation, and that would avoid the tedious and expensive operations of the all-fire process, would find ready acceptance among assayers. The method described by Dr. Godshall seemed to offer some possibilities in this direction. To test the practical accuracy of this method, comparative assays were made in my laboratory on three samples of bar-copper, using the “combination-method” for silver, and the “all-fire” process for gold, alongside of Dr. Godshall’s method. Some preliminary experiments were made by the new method to obtain a knowledge of any peculiarities that might be developed. The process of assay was as follows: One A. T. of borings dissolved in dilute nitric acid (90 c.c. strong to 100 c.c. of water). The solution was then evaporated to expel free nitric acid, a little sulphuric acid (20 c.c.) was added, and the evaporation continued. Finally the copper salts were dissolved in hot water, the solution diluted to 800 c.c., and allowed to cool. Then sulphuretted hydrogen was passed rapidly into the liquid for two minutes. A heavy black precipitate of sulphides was produced, which settled rapidly, leaving a clear blue solution. The liquid containing the precipitate was stirred rapidly and then allowed to settle for about half an hour, and finally the sulphides were filtered off. The filtrates in most cases gave no visible reaction for silver; sometimes, however, silver was not completely precipitated by the sulphuretted hydrogen. No reason was developed why this should be the case, as those solutions which contained silver had apparently been treated exactly like those which did not. The assays noted below did not show any reaction for silver when the filtrate was tested with salt-solution. The copper sulphide containing the silver and gold was dried, the papers burned in scorifiers, and the residue scorified with 50 grammes of test-lead. The results were as follows.

Silver—Ounces per Ton.

	Godshall Method	Combination Method
No 1,	67 70	67 20
" 2,	57 20	58 80
" 3,	59 00	59 30

Gold—Ounces per Ton.

		All-Fire Method
No 1,	2 28	2 42
" 2,	1 89	2 10
" 3,	2 06	2 18

From the foregoing results one would infer that the new method can give good results on silver. But the gold-assays are too low, being about the figures which would be obtained by parting the silver-beads obtained by the "combination-method." The new method does not seem to possess any advantage over the "combination-method" in point of speed. When the silver chloride is stirred well or "blown down" with air, it can be filtered off as quickly as the sulphide precipitate. On the other hand, the new method requires the use of sulphuretted hydrogen, which is a noxious and troublesome reagent to handle on a large number of samples at the same time.

CABELL WHITEHEAD, Washington, D. C. (communication to the Secretary): Dr. Godshall has placed the metallurgical public under great obligations by reviving the subject of the determination of gold and silver in copper-bearing materials. Several years ago Dr Ledoux brought this subject before the Institute in a valuable paper, but I have always felt that the subject was not as fully discussed at that time as might have been done with profit. It was clearly shown by the results then reported that the "combined" method yielded lower gold-results than the fire-assay. This was supposed to be due to a solution of some of the gold, occasioned by the impurities in the nitric acid used; and Dr. Godshall seems to have accepted that view. Since then, I have determined by experiment that when the acid is chemically pure, a partial solution of the gold takes place, probably by reason of the formation of nitrous acid during the process of solution, and that the reaction, though manifested in smaller degree, is closely allied to that which occurs when platinum, in the form of an

alloy, is dissolved in nitric acid. This being admitted, it is clear that the "combined" method cannot be relied upon for gold. We were therefore greatly in need of a method such as the one proposed by Dr Godshall. I have experimented with it, and find that, under certain conditions, excellent results are obtained. The conditions for satisfactory working are given in his paper, but I do not think the danger-points are clearly marked. I found that, when the solution was cold, and practically free from nitric acid, the precious metals were perfectly thrown down with a very small amount of H_2S . In such cases, the amount of copper to be removed by scorification and cupellation was small, and gave no trouble, but when the copper-solution contained much free nitric acid, or was hot, large amounts of H_2S were required to complete the precipitation, this had to be followed by a rapid filtration, and, even then, the solution frequently contained traces of silver. The removal of the nitric acid by evaporation with sulphuric acid is a matter of considerable difficulty, as I believe all who have tried it will admit. This and the careful attention required in making the H_2S precipitations are the chief objections to the method. I have modified it with good results as follows:

I dissolve in HNO_3 ; dilute and make faintly alkaline with ammonia; then make acid with acetic acid. I then add a solution of hypo-sulphite, sufficient to precipitate about 100 mgs. of copper. After thoroughly mixing the solutions with a stirring rod, the beaker is boiled for five minutes, or until the Cu_2S collects. This precipitate is cupelled in the usual way. With this modification of the proposed method, I believe there remains only one objection, viz., the necessary scorification of a product high in copper. I have been working with some success to overcome this difficulty, and I hope to publish the result of my efforts hereafter.

Pyritic Smelting in the Black Hills

Discussion of the Paper of Dr Franklin R Carpenter. (See p 764)

H. VAN F. FURMAN, Denver, Colo (communication to the Secretary). There are some statements in Dr Carpenter's interesting paper which appear to require explanation, if not modification.

He says (p. 766) "I have figured the alumina as a base, as we always did in our work at Deadwood" Personally, I have had no experience with slags of the particular composition given by Dr. Carpenter in his Table I, but my experience with the more basic, and more ferruginous, slags of lead- and copper-smelters has satisfied me that in these slags alumina invariably acts as an acid, and should be so considered in calculating the furnace-charges. My recent experience in lead-smelting at Mapimi, Mexico,* where the ores contain high percentages of alumina, has confirmed this opinion. The slags which I made there generally contained from 12 to 14 per cent of alumina, while the silica ranged from 28 to 32 per cent. The slags carrying 23 per cent of silica exhibited all the characteristics of basic slags, as judged from the standpoint of the lead-smelter, but they were fairly clean in lead and silver, ran pretty well, and kept the blast-furnaces in tolerably good condition. I am satisfied that, if the alumina had played the part of a base in these low-silica slags, it would have been impossible to keep the furnaces open and running successfully. Whenever the silica exceeded 30 per cent, these slags exhibited all the characteristics of what the lead-smelter would consider an acid slag; and I found it not advisable to try to run the furnaces on a charge higher in silica. In ordinary lead-smelting practice, with from 2 to 4 per cent. alumina in the slags, it is not unusual to find in the latter from 33 to 36 per cent. of silica. It may be of interest to note that the best results which I obtained in smelting these Mexican ores were with slags having approximately the following composition: SiO_2 , 28; $\text{FeO} + \text{MnO}$, 36; CaO , 16; and Al_2O_3 , 14 per cent.

The lead-smelting practice of Denver and Pueblo, Colo., has been considerably modified since the smelters have been compelled to treat large quantities of Cripple Creek ores, which carry considerable percentages of alumina. Formerly the practice was to make slags containing from 33 to 35 per cent. of silica. At present, with large quantities of aluminous ores in the charge, the slags seldom contain more than 31 per cent. of silica, yet they present all the physical characteristics of the former high-silica slags. This would apparently indicate that in the Colo-

* "Notes on Mining and Smelting in the State of Durango, Mexico," by H. Van F. Furman, *Proc. Colo. Sci. Soc.*, Jan., 1900.

rado practice of to-day the alumina replaces silica, and consequently plays the part of an acid

As regards the employment of dolomite, or magnesia-bearing ores as flux, I may observe that magnesia has been quite generally regarded by lead-smelters as something to be avoided. Hofman, in his *Metallurgy of Lead*,* says

"Magnesia is undesirable in a lead-furnace, as it makes a slag pasty and streaky, but in many cases the only available limestone is dolomitic, and it must be made the best of. This undesirable property of magnesia is especially observable if the slag contains zinc. Magnesia and zinc oxide appear to intensify each other's property of being difficult to slag. If a slag contains 8 per cent. zinc and from 2 to 3 per cent. baryta, very common just now in Colorado, from 2 to 3 per cent. magnesia shows a decidedly bad effect, and 5 per cent. causes a great deal of trouble and is liable to chill. This is perhaps to be explained by the fact that the silicate of magnesia has a higher specific heat than the silicate of lime, and ought to be corrected by more fuel."

In view of the high-magnesia slags which Dr. Carpenter describes, and also in view of the fact that in Colorado it is not unusual at present to find modern, large lead blast-furnaces running on slags carrying zinc, 6; baryta, 2, and magnesia, 4, or more, per cent., the above statement should be modified. In the use of magnesia as a flux, it should be remembered that it is a more powerful base than lime, and, in the calculation of the furnace-charge, if lime be taken as 1, the factor for magnesia will be 1.4. In other words, 1 part of magnesia will satisfy the same number of parts of silica as 1.4 of lime.

Dr. Carpenter lays great stress upon the advantages of producing iron sows in so-called pyritic smelting. To the lead- or copper-smelter, this is somewhat startling. It is a fact that in the early days of lead- and copper-smelting in the United States the production of iron sows was not unusual. They were not wanted, but they were often made, and were regarded by many as necessary evils. I believe that the production of iron sows is a rare occurrence at present, and I doubt whether the lead or copper blast-furnace manager of the present day would hold his position long if he should produce many such sows.

Is it not possible that the addition of more pyrites to the furnace-charge, and a proper control of the coke-charge and the blast, would have done away with the formation of sows at

* Fifth edition, page 286.

Deadwood? Dr. Carpenter says that the production of iron sows was desirable, because they proved to act as collectors for the gold, and thus reduced the gold-losses in the slags. Could not the slags have been rendered clean by the addition of small amounts of copper and additional pyrites to the furnace-charge? Of course, this would be copper-matte smelting, and we are familiar with the results obtained by that method. It appears to the writer that the practice suggested would be preferable, from both a metallurgical and a commercial standpoint, wherever copper-ores or mattes could be obtained. If I am reliably informed, it has been the practice for a number of years past, at Deadwood, to add copper-bearing material to the furnace-charges.

FRANKLIN R. CARPENTER, Denver, Colo. (communication to the Secretary) In reply to the statements of Mr. H. Van F. Furman, I would say, concerning alumina and magnesia, that in the opinion of most, if not all, metallurgists, alumina is sometimes a base and sometimes an acid. The minerals called spinels show conclusively that alumina acts as an acid, while the ordinary silicates of alumina show that it may act as a base. It may be that its position is determined by the quantity and kind of the remaining bases. It will be noticed (page 766 of my paper) that the ferrous oxide in the Mansfeld slags is very low. In such slags alumina is undoubtedly a base, replacing iron. I have taken the average of the Mansfeld slags, and figured alumina as an acid. The oxygen in the acid to the oxygen in the base is as 3.66 to 1. The silicate degree is 0.55 to 2.0—not much short of a quadrisilicate—hardly such a silicate as one would think would flow from the blast furnace—yet these slags are fairly fluid, and melt readily. The slag, as noted in my own table under date of September 9, 1895, being figured in the same way, gives 2.1 to 1 as the oxygen ratio, and the silicate degree as 0.95 to 1, or that of a bisilicate. A slag of this character does not seem bad for a blast furnace, but the Mansfeld slag seems very improbable. I believe, however, it has been concluded that the Mansfeld slag consists of monosilicate of alumina plus bisilicates of the RO type.

At Cripple Creek the ores have the general analysis:

	Per cent
SiO_2	60 to 62
Al_2O_3	17 " 18

	Per cent
Na ₂ O and K ₂ O,	12 to 13
S,	2 " 3
Fe,	2.5 " 3.5
MnO,	0.5 " 1
CaO,	0.7 " 1.2
MgO,	0.4 " 0.6
Cu,	0.005 "
H ₂ O,	1.0 " 2.0

I designed the Florence plant to treat these ores, and I expected to make Mansfeld slags. There was no essential difference save the percentage of alkalis. These I supposed would be of great advantage, as we considered potash as a powerful flux, and, also, as one that would make slags fluid. I resorted to my crucible-method, and made the following experimental slags

	SiO ₂ Per cent	FeO Per cent	Fe Per cent	Al ₂ O ₃ Per cent	CaO Per cent	MgO Per cent	K ₂ O Per cent	Na ₂ O Per cent
1,	45.4	13.6	10.6	14.9	10.4	6.5	6.5	65
2,	47.6	9.5	7.4	16.8	11.2	6.6	5.4	62
3,	53.4	3.6	2.8	18.4	9.8	6.7	6.1	1.15
4,	53.2	2.8	2.2	19.1	9.3	5.7	7.1	1.65
5,	49.2	9.77	7.6	14.6	10.5	5.6	7.1	1.60
6,	54.2	2.3	1.8	19.1	9.3	5.6	7.0	1.40
7, .	50.2	12.5	9.7	12.7	10.4	6.6	5.6	42

These slags appeared fluid, and, I did not doubt, would flow freely from the furnace; but the sequel showed that they would not do so. The furnaces could not be kept open. In the crucible the slags appeared fluid; but in the furnace they were very viscous, unless superheated, when they became thin. The frozen furnaces were found to be full of chilled slag—very good-looking slag, too—"from bottom to gunwale," showing that the slags formed readily, but would not run from the furnace. I was forced to abandon a 50-per cent. silica slag for these ores, although it had been made at Deadwood (with less alumina), and at Mansfeld (without alkalis, and with less magnesia). I then figured my slags as do the Bessemer steel people:

$$\frac{RO = (CaO + MgO + \text{etc.})}{SiO_2 + Al_2O_3} = \frac{48}{52} \text{ to } \frac{52}{48}$$

These slags ran when hot, but chilled very easily, and the furnaces were lost in the same way as before, *i.e.*, they were

full of slag, so viscous that it had failed even to run into the tuyeres!

It should be remarked that in Colorado the Cripple Creek ores are used but sparingly by the local smelters. While 15 per cent. of the charge may be of Cripple Creek ores, the slags are notably viscous, while 20 per cent is about as large a percentage as the lead-smelter cares to add to his charge. The ores form, when smelted alone, with ordinary fluxes, a very viscous slag. When added to other ores, they impart this property of viscosity to the slags directly in proportion to the amount used. I advance the somewhat heterodox idea that the potash and soda, and not the alumina, make the trouble. My reason will be seen later. In my Cripple Creek practice everything tended toward lowering the fusing- or formation-point of the slag. By reference to the Hofman curves (*Trans.*, xxix., 682) it will be seen that this is the effect of high silica and high alumina, while it is elementary knowledge that the alkalis do the same thing. I had, then, the somewhat unusual condition of a slag forming at too *low* a temperature, or, at least, at a temperature at which it was not fluid. I had, therefore, to construct a slag that would have a higher formation-point, or, at least, a formation-point at which it would be fluid. By reference again to the Hofman curves, it will be seen that there is only one base, ordinarily obtainable, which will raise the formation-point, and that is the much-dreaded magnesia. By proper use of this I secured a slag which was fluid *at its formation-point*, and satisfactory in every way. So far as I am aware, this work is original. I think, therefore, that the trouble which smelters have with the Cripple Creek ores is due, not to their refractory nature, but to their low fusing-point, and the difficulty of superheating them in the blast furnace. They soften easily in the upper part of the furnace; and, when combined with the other slag-forming constituents of the charge, they form a slag made at a much lower temperature than would be made without them, but, unfortunately, at a temperature at which they are not fluid. The present Florence slags are far more liquid than ordinary lead-slugs, and are all far more fluid than the Deadwood and the Mansfeld slags, both of which are somewhat viscous. The Florence slags run forward when poured over the dump, making not

more than a 30°-slope, while those at Deadwood make a 90°-face to the dump. I have received many private communications from metallurgists concerning my use of magnesia, which I should like to use; and, as Prof. Furman quotes Dr. H. O. Hofman, it may not be a violation of confidence to say that the latter fully agrees with me that magnesia is a desirable base in the presence of much alumina, while a reference to page 130, Part I, of Collins' recent work upon the *Metallurgy of Lead*, shows that he also considers it less objectionable when alumina is present. According to the Hofman curves, it will be seen that they cancel each other's effects; but there is, I think, an advantage, pointed out long ago by Overman, in the mere multiplication of bases: that is, that a polybasic slag is to be preferred to one containing but one base, or few bases.

Iron Sows—Mr. Furman's objection to iron "sows" comes largely from a misunderstanding of the process, and this arises again, doubtless, from the now very misleading term "pyritic smelting." It is very different, also, from the lead-and-copper process to which he makes reference, which treats mainly oxidized or roasted ores. Singular as it may seem to Mr. Furman, the difficulty cannot be overcome by the addition of pyrite or copper, as he suggests, and the addition of such material only aggravates the trouble. It must be remembered that this sort of pyritic smelting has nothing to do with the smelting of pyrite-ores as a business; the sulphide material being added for an express purpose, and at a loss, and the cost of smelting being borne wholly by dry siliceous ores. This is the case at Kongsberg, Norway, at Florence, Colorado, and at Deadwood, So Dakota. We have a prior right to the term Pyritic Smelting, and it is most unfortunate that those who follow the footsteps of Hollway, who first tried to smelt pyrite-ores by means of their heat-producing constituents, did not adopt some other term, although I suppose it is now too late to worry about it. If the difference between the Deadwood process and the Hollway process is borne in mind, what follows will be understood. In the first, the charge consists of earthy matter, which, to be fused, calls for much coke, while the smelter of pyrite-ores (Hollway process) prefers to smelt by aid of the heat derived from the combustion of sulphur, iron, etc. The Deadwood process requires a reducing atmosphere—the Hollway an oxi-

dizing one, to the extent that if the presence of any coke could be avoided it would be better. In the Deadwood process the coke which is consumed before the tuyeres is burned at a temperature of about $1400^{\circ}\text{C}.$, and can, therefore, be burned to CO only. At Mansfeld, where much study has been made of this subject, the gases pass off, carrying from 16 per cent to 18 per cent CO

At Deadwood but three kinds of material go into the charge.

1. Dry siliceous ores.
2. Dolomite.
3. Pyritiferous material.

The last serves the double purpose of furnishing ferrous oxide for the slag and sulphide for the matte. An excess of pyrite causes, as at Kongsberg, an increase in the formation of iron-deposits, but if this material went into the furnace oxidized, as in the lead-and-copper process familiar to Mr Furman, less iron-deposits would be formed. In the first case, which we had better call "raw smelting," Samuelson states that the excess of pyrites causes "sulphide of carbon to be abundantly developed, which has a strong reducing action upon oxidized iron, forming Fe_2S (old nomenclature), which is then decomposed into Fe_2S and Fe." Further on in the discussion of the leading of the matte, he says "The formation of iron-deposits increases in proportion as the roasted raw matte diminishes, this is the reverse of what takes place in the raw smelting;" and, "A larger addition of roasted matte, *i.e.*, iron oxide, again dissolves the iron-deposits formed, and for the following reason. one part of carbon only possesses a definite smelting and reducing action by which the iron-deposits are formed; if more sulphur-etched raw matte is used, its metallic sulphides will remain undecomposed, and the sulphur it contains has a solvent action upon deposits which have been already formed."* Mr. Van Furman, therefore, would be more nearly right if he advised the addition of more iron oxide instead of more iron sulphide.

At Mansfeld, where the copper matte runs from 37 to 44 per cent. in copper, these sows are formed. Iron matte has not been

* See Crookes and Rohrig's *Metallurgy*, vol. 1, pp. 225 and 235

made at Deadwood since 1895 Our first matte usually carried about 12 to 15 per cent. of copper, and the second matte about 30 per cent.; but the matte did not prevent the formation of reduced iron, nor the presence in this reduced iron of at least as much gold as in the matte. All the metallurgical skill of the German Empire has not overcome the formation of sows at Mansfeld—they are inseparable from the process.

The Elimination of Impurities from Copper Mattes in the Reverberatory and Converter.

Communication from Prof H. M. Howe, in correction of his previous Contribution to the Discussion of Mr Keller's paper (*Trans*, xxviii, 832)

IN discussing Mr. Keller's paper, I quoted the results obtained by Mr. Allan Gibb, correctly crediting them to Mr. Gibb, with due reference to the report in which they were published. But in the table immediately following, and in my further remarks, following the table, I find that, by some clerical or other error which I cannot, after the lapse of time, explain, I spoke of Mr Gibb as Mr. "Dean"—a metallurgist who had written on a related subject, but not on the point I was discussing. In short, my reference throughout was to the work of Mr. Gibb, and by reading "Gibb" for "Dean" in all places on pp. 832 and 835 where the latter name occurs, my remarks will be brought into accordance with my intention, and with the facts.

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[NOTE —In this Index the names of the authors are printed in small capitals, and the titles of papers in italics. Casual references, giving but little information, are usually indicated by bracketed page-numbers.]

ERRATA

1 In Vol xxviii, pp 832, 835, certain work is credited by Prof H. M. Howe to "Mr Dean" which was done by Mr Allan Gibb. See Prof Howe's correction on p 1133 of this volume.

2 In Vol xxix, p 901, Mr H. B. Edwards is called the manager of the Mountain Copper Co, at Keswick, Cal. On page lxvii of the same volume, Mr Edwards is correctly mentioned as assistant manager.

3 In the present volume, on p xlviii, the list of papers read by title at the Canada meeting should contain the paper by Mr J. B. Davis on the history of Solar Surveying-Instruments, which is printed on pp 803-837.

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